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Determination of the Effects of Ambient Conditions on CFM56 Aircraft Engine Emissions

General Electric Co, Cincinnati, OH Aircraft Engine Group

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16. ABSTRACT

It has been known that variations in ambient temperature, pressure, and humidity can have significant effects on measured emissions levels. Although the need to account for variation in ambient conditions is generally recognized, and several studies have attempted to establish more or less universal correction factors, there is no widely accepted procedure for the correction of emissions measurements to reference-day ambient conditions.

A current program by the EPA is to establish a wide data base from which procedures for correction of measured emissions levels to reference day conditions can be developed. To establish this data base, EPA contracted with three engine manufacturers to make tests under controlled ambient conditions. To supplement these data, industry and other government agencies were requested to submit data that could be used in establishing an acceptable correction procedure.

The CFM 56 engine was selected for this study because it is representative of the next engine of highly efficient, large turbofans which will be in production when EPA gaseous emissions standards first become effective in the early 1980's.

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1.0 INTRODUCTION

Since the earliest studies of aircraft engine pollutant emissions, it has been known that variations in ambient temperature, pressure, and humidity can have significant effects on measured emissions levels. These factors have been recognized in EPA regulatory actions (Title 40 Code of Federal Regulations Part 87) which have established emissions standards and measurement procedures for control of air pollution from aircraft engines. Although the need to account for variation in ambient conditions is generally recognized, and several studies have attempted to establish more or less universal correction factors, there is no widely accepted procedure for the correction of emissions measurements to reference-day ambient conditions.

Part of the problem in establishing correction procedures has been that the relatively large variation in measured emissions due to other factors has tended to mask the variation due to changes in ambient conditions. These other factors can generally be classified as measurement precision, engine-to-engine variability, and test-to-test variability on the same engine. Additional complexity is introduced by the fact that changes in ambient temperature, pressure, and humidity can result in changes in engine emissions levels due to two separate effects. The first is a direct effect on combustor inlet conditions which influence engine emissions. The second is due to changes in engine operating conditions (rotational speed, airflow, etc.) which, in turn, affect combustor operating conditions and, hence, emissions. Therefore, the most productive approach is to focus on the primary variables which determine the magnitude of emissions levels (that is, combustor inlet conditions which may be affected by ambient conditions).

The current program is part of an ongoing effort by the EPA to establish a wide data base from which procedures for correction of measured emissions levels to reference-day conditions can be developed. To establish this data base, EPA contracted with three engine manufacturers to make tests under controlled ambient conditions. To supplement these data, industry and other government agencies were requested to submit data that could be used in establishing an acceptable correction procedure. The status of this EPA effort has been reported in References 1 and 2.

THe CFM56 engine, currently under development, was selected for this study because it is representative of the next generation of highly efficient, large turbofans which will be in production when EPA gaseous emissions standards first become effective in the early 1980's. For this engine, compliance with EPA noise and emissions regulations has been an important consideration ever since development began.

2.0 SUMMARY

The effects of ambient temperature, humidity, and pressure on the emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), and smoke from a CFM56 engine combustor have been determined through rig tests in which combustor inlet conditions could be carefully controlled. In addition, these data were verified in full-scale engine tests under uncontrolled ambient conditions.

In the CFM56 combustor rig tests, emission levels of CO, HC, NO_x, and smoke were measured over a range of inlet-air humidity, a range of simulated engine-inlet-air temperatures, and a range of simulated barometric pressures at each of five simulated engine-power settings from idle to takeoff thrust. These tests were run in an existing high pressure combustor test facility at the General Electric Evendale, Ohio, plant. In order to obtain the required range of humidity, an inlet moisture measurement and control system was added to this facility. The highest simulated engine-power conditions, climb out and takeoff, were run at reduced pressure due to test facility limitations. The combustor was mounted in an existing high-pressure combustor test rig which provides an exact duplication of the CFM56 engine flowpath.

For each test condition, emissions measurements were made twice. A total of 214 separate test points were run. The combustor test conditions, along with the measured emissions levels, were transmitted in computer-readable format to another EPA contractor (Calspan Corporation) for subsequent analysis of the data (Reference 1).

The engine-test phase of the program involved verification of the rig test by emissions testing of a full-scale CFM56 engine using a combustor identical to that used for the rig tests. The engine tests were conducted under uncontrolled ambient conditions, but maximum advantage was taken of daily and longer term variations in atmospheric conditions in order to obtain as wide a range of ambient levels as practicable. Six separate tests were run, each consisting of the same five power levels used in rig tests. Emissions levels measured in the engine tests were corrected for ambient conditions using factors derived from the rig tests.

3.0 CFM56 ENGINE DESCRIPTION

The CFM56 is a modern, high-bypass-ratio, turbofan engine being developed by CFM International. CFM International is a new company, jointly owned by General Electric and SNECMA (France), and was established to integrate and manage the design, development, marketing, production, and product support of the CFM56. In addition to the high bypass ratio, major features of the CFM56 are high component efficiencies and low weight - aimed at combining good performance with low noise and emission levels, low operating costs, and high productivity. The engine is fully modular in construction.

Figure 1 is a photograph of the basic development engine, and Figure 2 shows the engine installed with a confluent exhaust system in which the fan and core streams are routed through the same nozzle. The CFM56 is a dual-rotor engine with single-stage fan, three-stage compressor, and four-stage low pressure turbine on the low pressure rotor. The high pressure section consists of a nine-stage compressor, annular combustor, and single-stage turbine. The core engine is basically the same as that of the U.S. Air Force F101 engine for the B-1 bomber.

The combustor of the CFM56 is extremely compact and has a high combustion space rate at rated sea level static takeoff operating conditions. The fuel injection system is of the air-blast type with low-pressure central fuel injectors.

The CFM56-4B model is rated at 24,000 lbf takeoff thrust (uninstalled) at sea level static and is flat rated to 86° F ambient temperature. This version of the engine has 6 to 1 bypass ratio and 29 to 1 pressure ratio at takeoff power. For purposes of the subject test program, the 22,000 lbf version of the engine was simulated (Model-1B). This version of the engine has 6 to 1 bypass ratio and 25 to 1 pressure ratio.

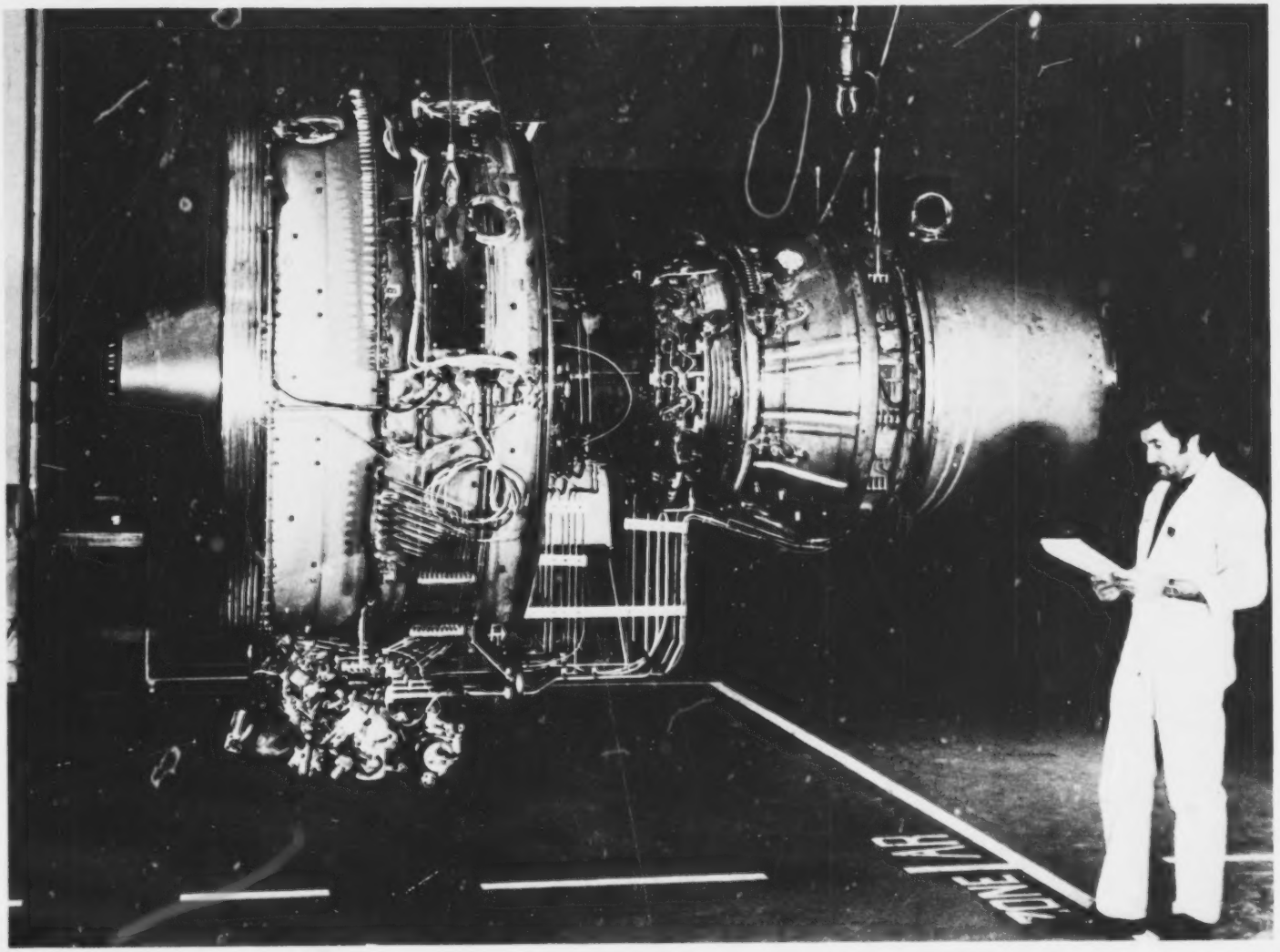


Figure 1. CFM56 Turbofan Engine.

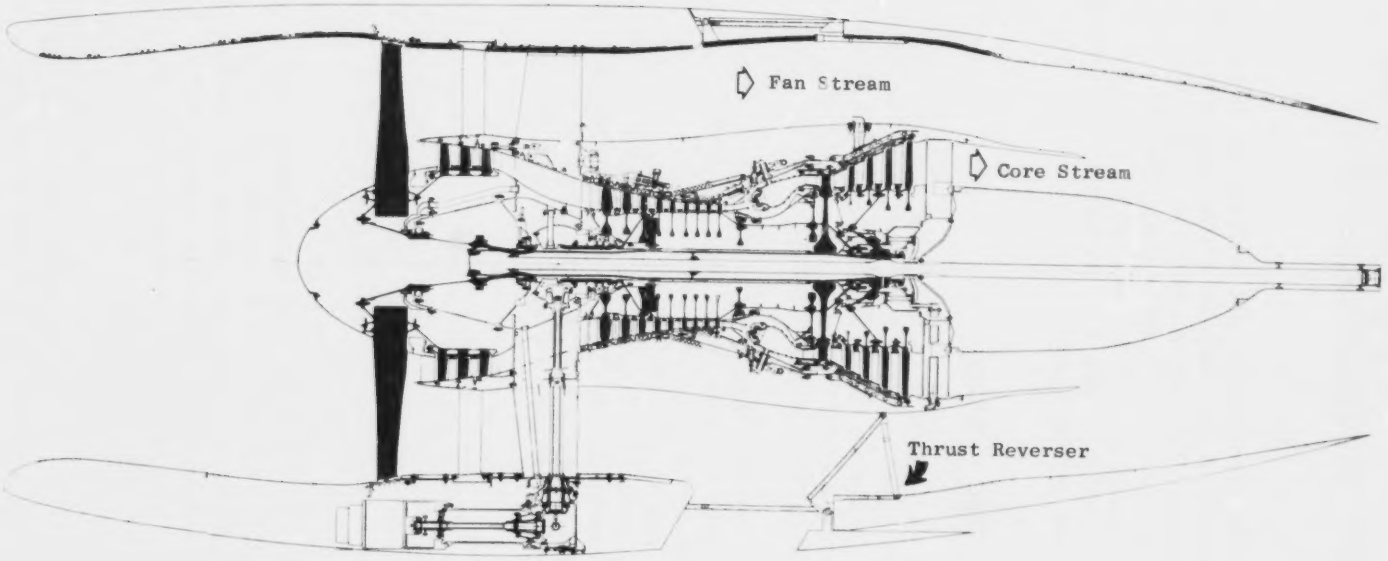


Figure 2. CFM56 Turbofan Engine Cross Section.

4.0 CFM56 COMBUSTOR RIG TESTS

The facility, measuring equipment, and procedures used for the CFM56 combustor rig tests were basically the same as those previously developed by General Electric for emissions testing of various combustion systems. The inlet humidity measurement and control system was the only major new capability required for this program. This section of the report describes the test facility, measurement system, and data reduction methods along with the results of the combustor emissions tests.

4.1 CFM56 COMBUSTOR RIG TEST FACILITY

The CFM56 combustor rig tests were conducted in Test Cell A3 at the General Electric Evendale plant. A schematic of the test cell and related facilities is presented in Figure 3. This cell was specifically designed for full-scale testing of large aircraft-engine combustors and is equipped to duplicate a wide range of operating conditions.

Air is supplied to the test cell by a central air supply system that consists of five multistage centrifugal compressors driven by synchronous motors. With all five compressors operating, the system has a nominal capacity of 100 pps at 300 psia. Wider ranges of flow rate and pressure can be obtained by utilizing various series/parallel-staging configurations. For the CFM56 combustor tests, a three-compressor configuration providing a capacity of 48 pps at 190 psia was used. This configuration was selected to reduce the required electrical power consumption (which can be a limiting factor in cell availability).

Elevated combustor inlet temperatures typical of engine cycle conditions are obtained with an indirect-fired air heater capable of heating 80 pps of air at 350° F and 140 psia to 1220° F at an outlet pressure of 122 psia. A controlled heater bypass is provided to allow higher total flow rate at reduced temperature rise.

A compressor after-cooler system with solid-dessicant drying can reduce inlet air humidity to levels as low as 0.55 grains per pound (-40° F dewpoint). In order to obtain increased inlet humidity up to 175 gr/lb, as required for this test program, a deionized-water injection system was designed and installed in the test cell. With this system, domestic water is purified by a commercial "Tri-bed" deionizing system that reduces total impurity levels to about 0.5 parts per million. The purified water is pumped through a turbine-type flowmeter and then injected into the hot airstream downstream of the heater. The required water-flow rate in the system is determined by measuring the humidity upstream of the water-injection point and calculating water flow required to obtain the desired humidity. A second humidity measurement at the rig inlet is used to verify this calculation and assure that all injected water is evaporated. Figure 4 is a schematic of the humidity measurement and control system.

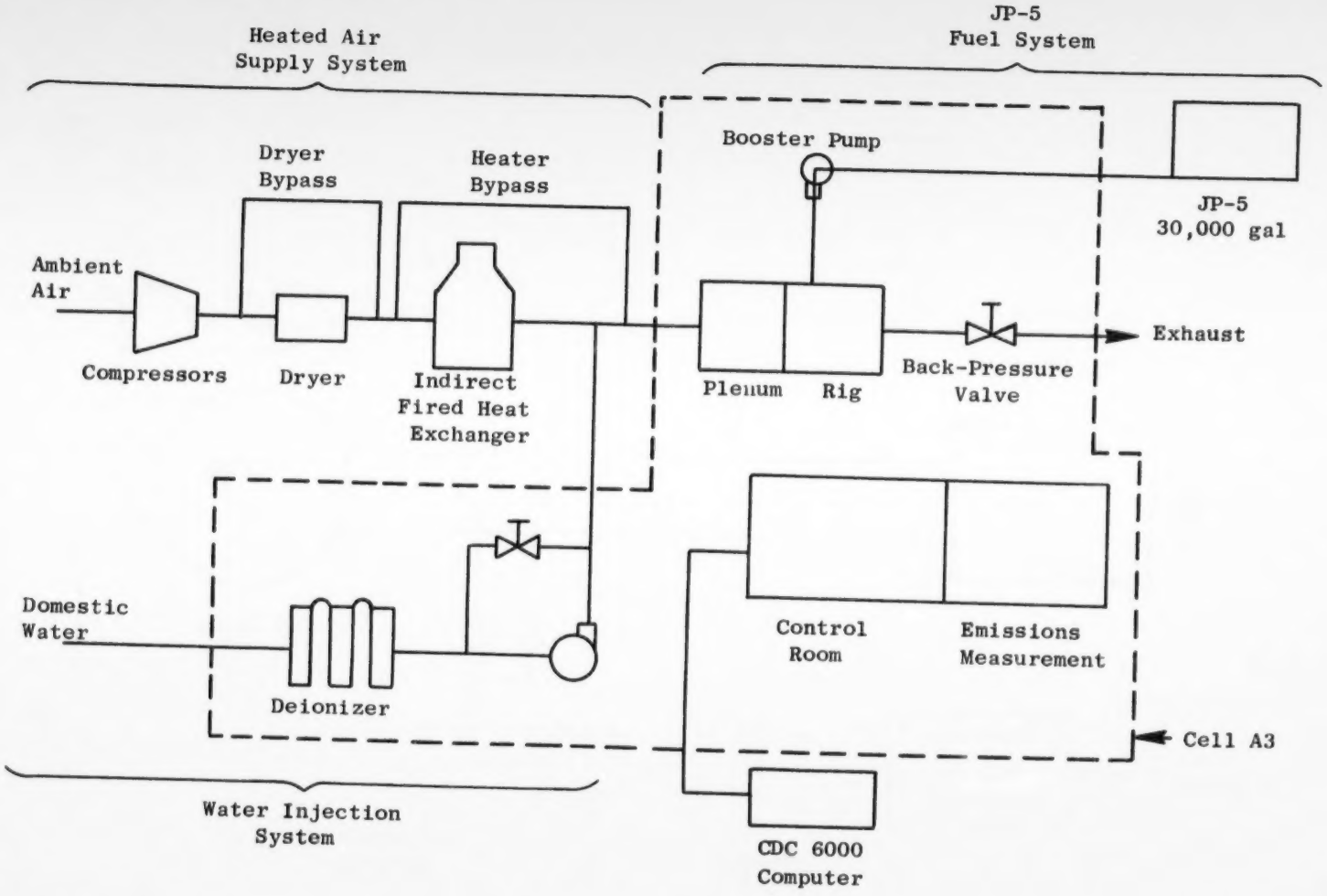


Figure 3. Combustor Test Facility.

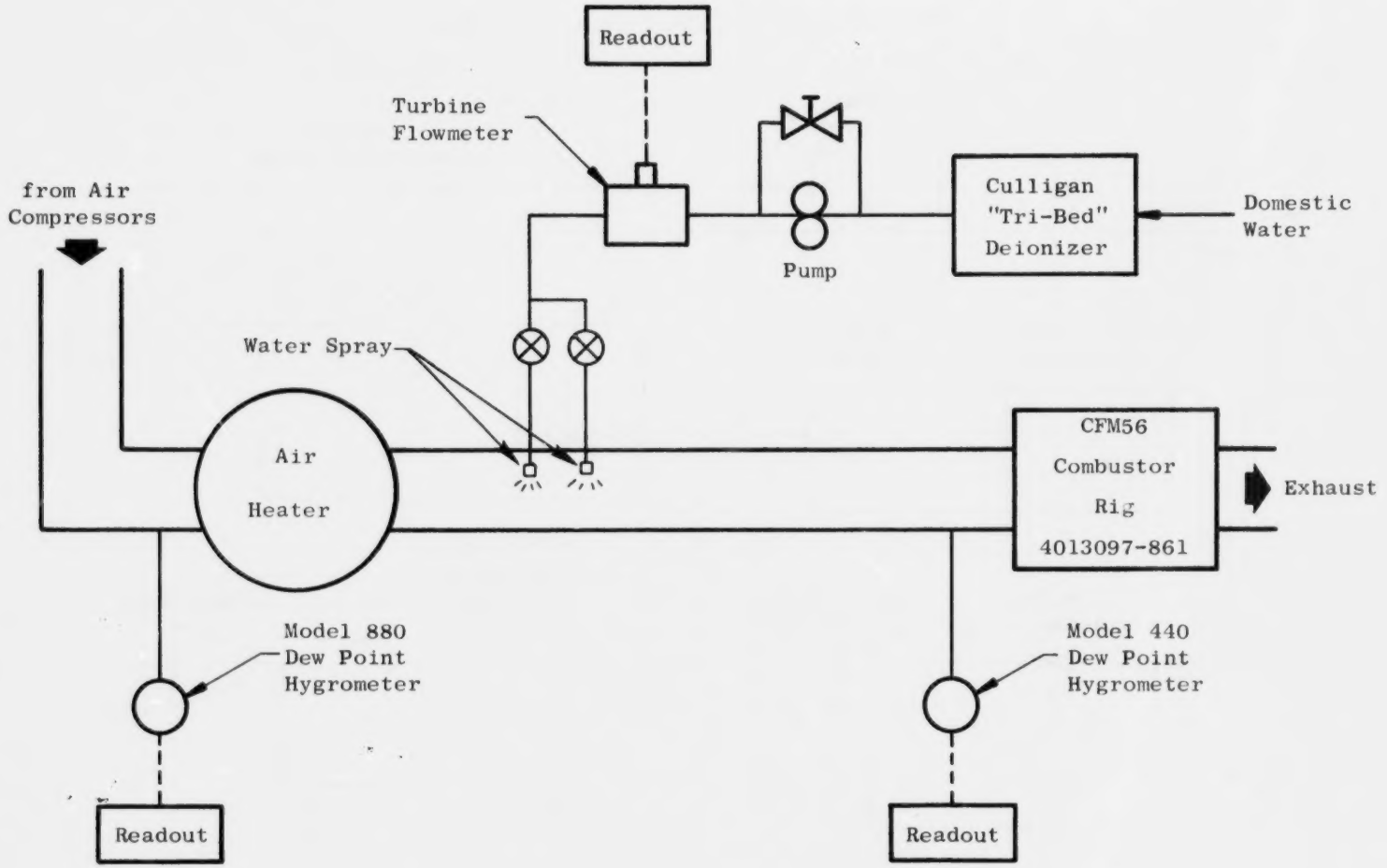


Figure 4. Humidity Measurement and Control System Schematic.

JP-5 fuel is supplied to Cell A3 from a remotely located 30,000 gallon tank. Booster pumps within the test cell provide fuel injection pressures up to 1200 psia.

Control consoles and data monitoring and recording equipment are located in a control room adjacent to the test cell. Up to 16 temperatures and pressures, as well as output from all gaseous-emissions analysis instruments, can be continuously recorded on strip charts. All pertinent operating and emissions data are input to the appropriate data-reduction program via a 900-channel, digital, data-acquisition system permanently installed in the control room. This apparatus scans each of the measured parameters in sequence, controls the position of pressure-scanning valves when required, converts the amplified d.c. signal of the measurement to digital form, and transmits this data to the time-sharing computer through a teletype terminal. During each scan, the overall voltage accuracy is checked against a precision potentiometer that has been calibrated in a standards laboratory. The digital voltmeter and low level amplifier are of sufficient quality that voltages are accurate to 0.02% of full-scale in the 0-10 millivolt range. Combustor and rig instrumentation input to the digital system are listed in Table 1.

CFM56 combustor emissions testing was conducted with a full-scale combustor mounted in an existing test rig. This full-annular test rig duplicates the flowpath of the CFM56 engine.

A cross-sectional view of the test rig with the combustor installed is shown in Figure 5. The test rig consists of an inlet plenum chamber, an inlet diffuser section, a housing for the combustor, and an exit spool which includes provisions for mounting of gas-sample rakes as well as exit pressure and temperature instrumentation. Ports and bosses to accommodate fuel injectors, igniters, and boroscope inspection devices are located exactly as in the engine design.

Air at temperature and pressure simulating compressor discharge conditions enters the rig through a flange bolted to the air-supply plenum. In the plenum, the flow is straightened by grates and screens. Air leaving the plenum is directed around a bullet-nosed centerbody into an annular passage that exactly duplicates the engine prediffuser.

Aft of the step diffuser, the centerbody forms the inner wall of the combustor housing. The combustor to be tested is positioned in the annulus between the centerbody and outer casing in a mounting system similar to that in the engine. Twenty fuel injector pads and two igniter pads, all configured to be accurate replicas of the engine pads, are located on the outer casing.

The exhaust end of the vehicle is provided with a large-diameter, sandwich-type flange that will accommodate either fixed or rotating instrumentation spools. For this test program eight fixed, gas-sample rakes were utilized (Section 4.2). The aft end of the instrumentation spool is connected to the facility exit section; this consists of a quench section, where the flow is cooled with water injection, and a water-cooled back-pressure valve.

Table 1. Combustor/Rig Instrumentation.

Parameter	Instrumentation	Digital System Input
Total Airflow	Standard ASME Orifice	Orifice Air Temperature, Upstream Pressure and Pressure Drop
Fuel Flow	Turbine Flowmeters (2)	Flowmeter Output Frequency
Fuel Injector Pressure Drop	Pressure Tap in Fuel Manifold	Fuel Pressure
Fuel Temperature	Thermocuple in Fuel Manifold	Fuel Temperature
Diffuser Inlet Total Pressure Inlet Plenum Static Pressure Diffuser Inlet Total Temperature	Single Point Total Pressure Probe Wall Static Taps (2) 3-Element Thermocouple Rakes (2)	Inlet Total Pressure Plenum Static Pressure Inlet Total Temperature
Inlet Plenum Total Temperature	Single Point Thermocouple Probes (2)	Plenum Total Temperature
Preheater Inlet Humidity (Upstream of Water Injection)	Dew Point Hygrometer	Dew Point
Inlet Plenum Humidity (Downstream of Water Injection)	Dew Point Hygrometer	Dew Point
Water Injection Flow	Turbine Flowmeter	Flowmeter Output Frequency
Combustor Exit Total Temperature	Single Point Temperature Probe	Exit Temperature
Combustor Exit Total Pressure	Single Point Total Pressure Probe	Exit Pressure
Combustor Exit Emissions Levels	CO, CO_2, HC, NO_x Analyzers	Range and Deflection
Combustor Dome Pressure Drop	Pressure Taps (4)	Dome Pressure Drop
Gas Sample Line Pressure	Pressure Taps (5)	Sample Pressures
Gas Sample Line Temperature	Thermocouples (10)	Sample Line Temperatures

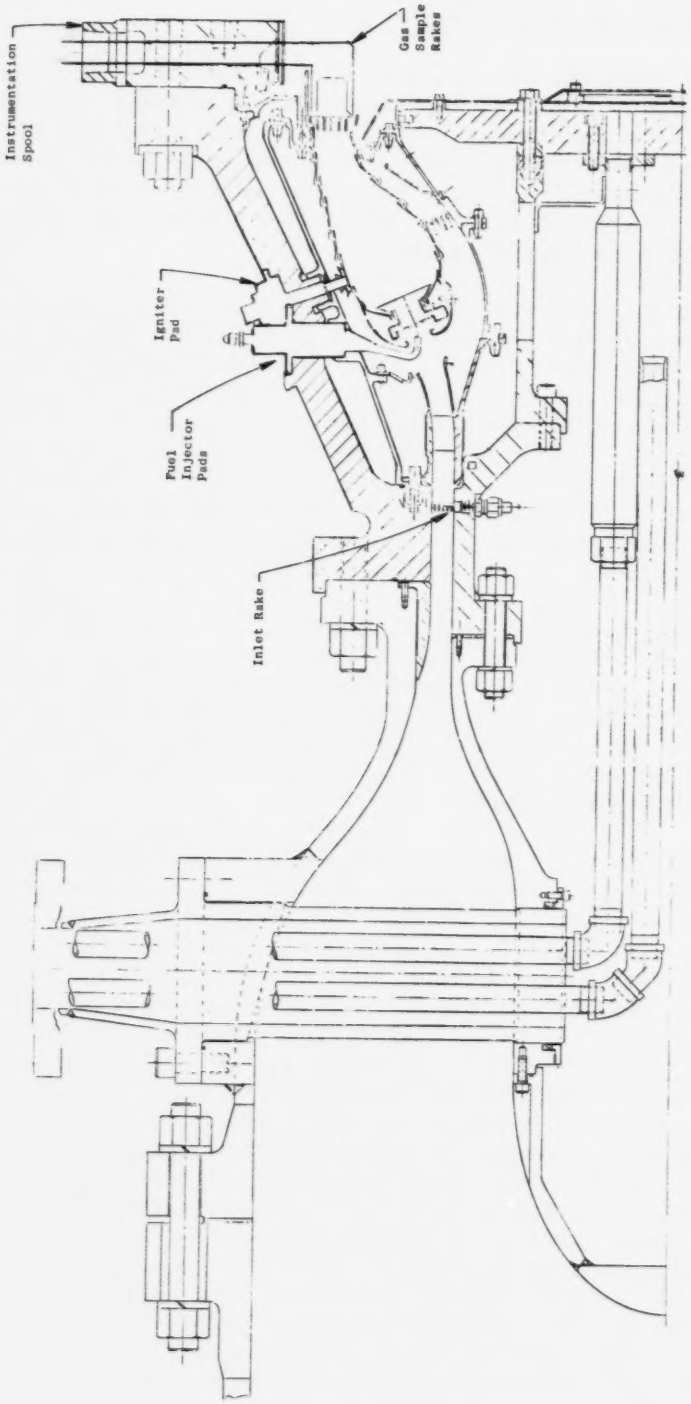


Figure 5. Combustor Test Rig Cross Section.

4.2 EMISSIONS SAMPLING AND ANALYSIS SYSTEM

The exhaust gas sampling and analysis system used in CFM56 combustor component tests consists of fixed, multicomponent, gas-sampling rakes; heated sample-transfer lines; a manifolding valve panel; and smoke and gas analysis instrumentation. All equipment and procedures are in accordance with EPA regulations for measurement of gaseous and smoke emissions from gas turbine engines (Reference 3) except for minor deviations required for combustor rig testing (as opposed to engine testing).

Gas samples for emissions measurement were drawn through eight fixed sampling rakes located at the combustor exit plane. The type of rake used is shown in Figure 6. Each rake contains five individual sampling probes spaced radially across the combustor exit annulus. The probe tips and rake body are water cooled to provide the necessary quenching of chemical reactions and to preserve the mechanical integrity of the rake in the high-temperature, high-pressure environment in which it must operate. Within the rake, steam heating is employed to prevent condensation of hydrocarbon compounds and water vapor in the sample lines. Sampling-rake construction, with steam and water flowpaths, is shown schematically in Figure 7.

Circumferential placement of the sampling rakes, shown in Figure 8, was selected to obtain representative samples. With the selected arrangement, there are two sampling locations in each quadrant of the combustor exit annulus. Since some cyclic variation is generally noted in emissions levels as a function of rake circumferential location relative to the fuel injectors, four rakes were positioned in line with the fuel-injection points, and the other four were positioned between cups.

Sample distribution is as shown in Figure 8. Individual probe samples are manifolded at the exit of each rake. The samples from each of the eight rakes are then lead to a bulkhead on the outer wall of the control room through approximately 15 feet of 0.125-in. O.D., 0.020-in. wall, stainless steel tubing. At the bulkhead, samples enter one of two main sample-line bundles that conduct the samples to the control valve panel in the test-cell control room. These bundles are approximately 40 feet in length and contain six 0.25-in. O.D., 0.028-in. wall, sample lines. Three-way valves in the control panel enable samples from any individual rake or combination of rakes to be routed to the gaseous emissions and smoke analysis instrumentation. Samples for gas analysis are routed through a 15-foot length of 0.375-in. O.D., 0.035-in. wall tube to the gaseous-emissions analysis instrumentation. Sample-line temperatures throughout the distribution system are maintained close to 300° F by steam tracing of individual sample lines, internal steam heating of the sample bundles, and electrical heating of the control-valve cabinet. Sample-line temperatures are monitored with thermocouples mounted on the rake manifolds and at the cell bulkhead. Sample-line pressures at these points are also monitored to allow calculation of the sample flow rate and assure adequate pressure drop across the probe orifices.

Figure 6. Quick-Quenching, Steam-Heated, Water-Cooled Probe.

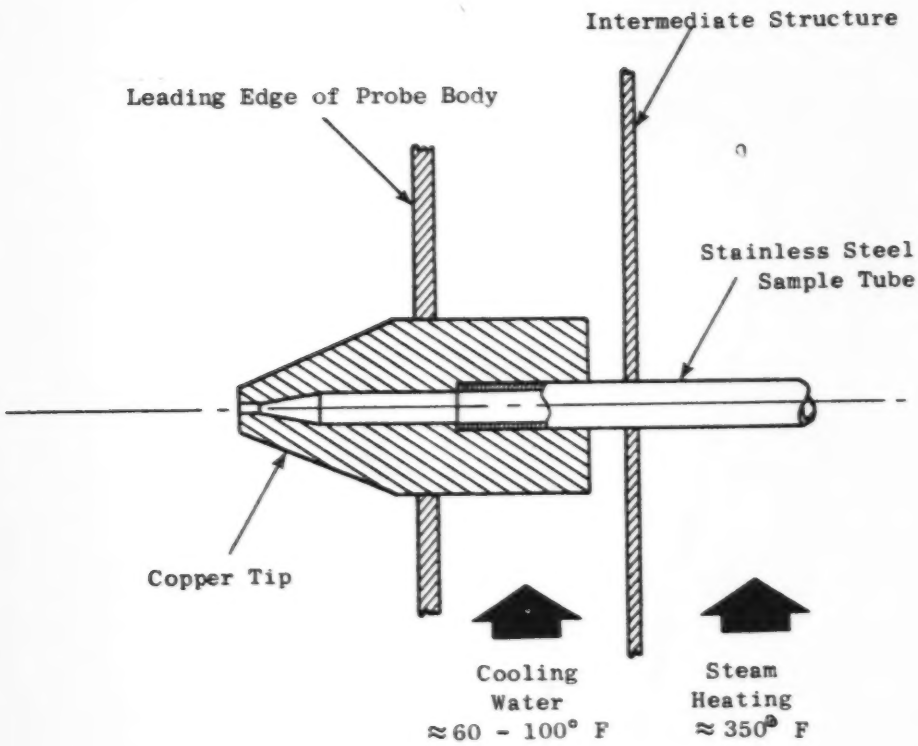
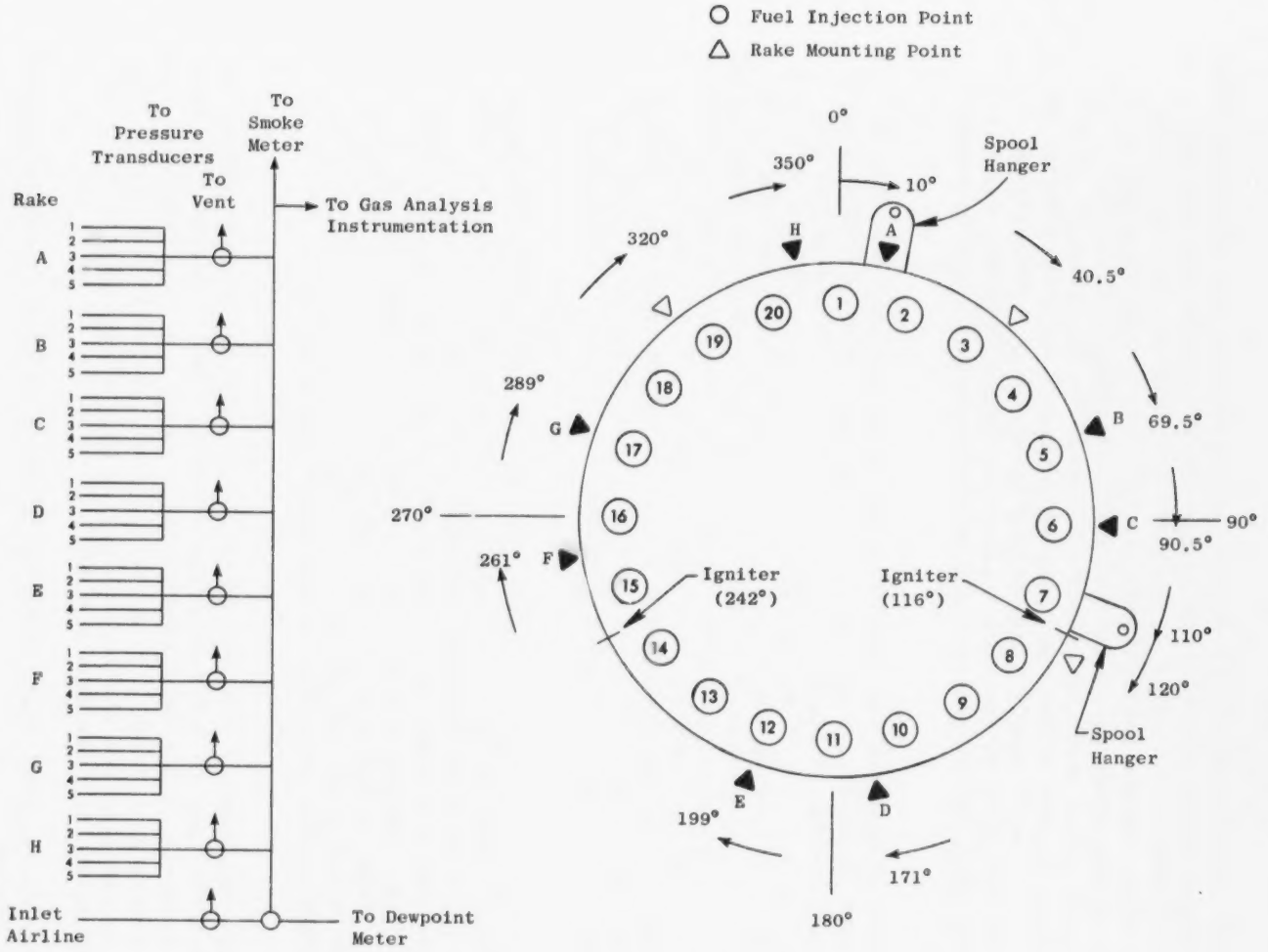


Figure 7. Steam-Heated, Water-Cooled, Gas-Sample Rake Schematic.



(a) Sample Line Manifolding

(b) Rake Positions, Aft Looking Forward

Figure 8. Sampling Rake Positions and Manifolding.

The normal sampling procedure during CFM56 combustor component tests was to obtain a ganged sample of all eight rakes for both smoke and gaseous-emissions measurements. In order to estimate the sample transit time for this sampling mode, sample dump flow at the inlet to the gaseous-emissions analysis section was measured at several different combustor operating conditions. Transit times were then calculated based on the measured sample-flow rate, sample system volume, and average measured sample pressures and temperatures. Estimated sample transit time is shown as a function of combustor inlet pressure in Figure 9. Based on dump flow alone, transit times were less than one second over the entire operating range encountered in rig tests.

Gas samples drawn from the combustor exit were analyzed for CO_2, CO HC, and NO_x with an existing, on-line, gas-analysis system. A flow diagram of this system is shown in Figure 10. In accordance with EPA procedures (Reference 3), none of the traps or dryers shown in Figure 10 were utilized during the combustor tests. All sample lines within the system downstream of the hydrocarbon analyzer were heated to 130° F to prevent condensation of water. Operation of the sample pumps shown in the system diagram was not required during rig tests because the high pressures at the rake inlet were sufficient to provide flow to the emissions instrumentation. A major portion of the sample flow is dumped at the system inlet in order to maximize flow rate in the sample lines and maintain a constant system-inlet pressure.

The four basic gas-analysis instruments in this system are a Beckman Model 402 heated flame-ionization detector for HC emissions, Beckman Model 315B and 864 nondispersive infrared analyzers for CO and CO_2 emissions (respectively), and a Beckman Model 951 heated chemiluminescence analyzer for NO_x emissions. Ranges and calibration gases used in each of these analyzers are shown in Table 2. A complete calibration of all instruments was conducted before each run and verified immediately following the run. During prolonged tests, instruments were zeroed and spanned at least once each hour.

Emissions measurement system-response times were obtained by adding the calculated transit time to 15% deflection response times measured with span gases input directly to the emissions-analysis section at the same flow rates used during combustor testing. This procedure was necessary because it was impractical to simulate the elevated pressures and temperatures seen by the emissions probes during combustor testing.

Total system-response times assuming the maximum (1-sec) sample-transit time were as follows:

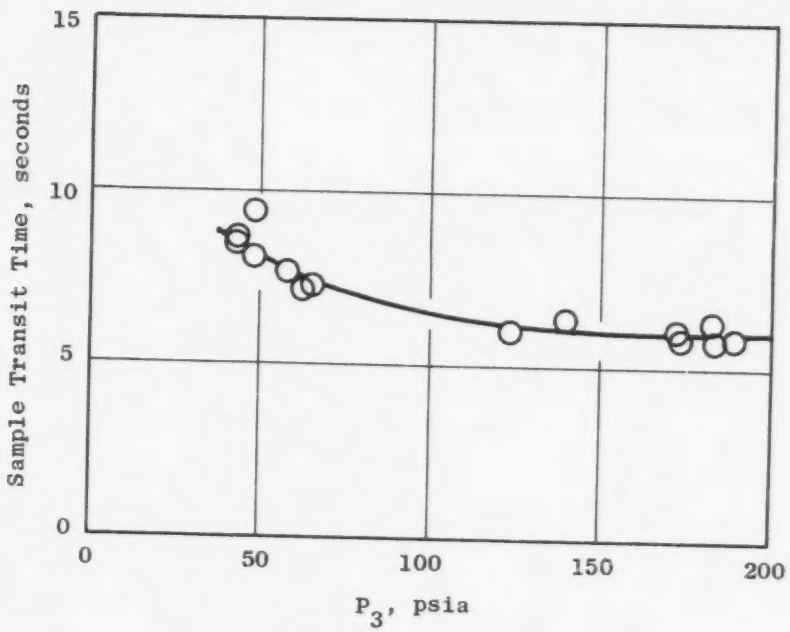
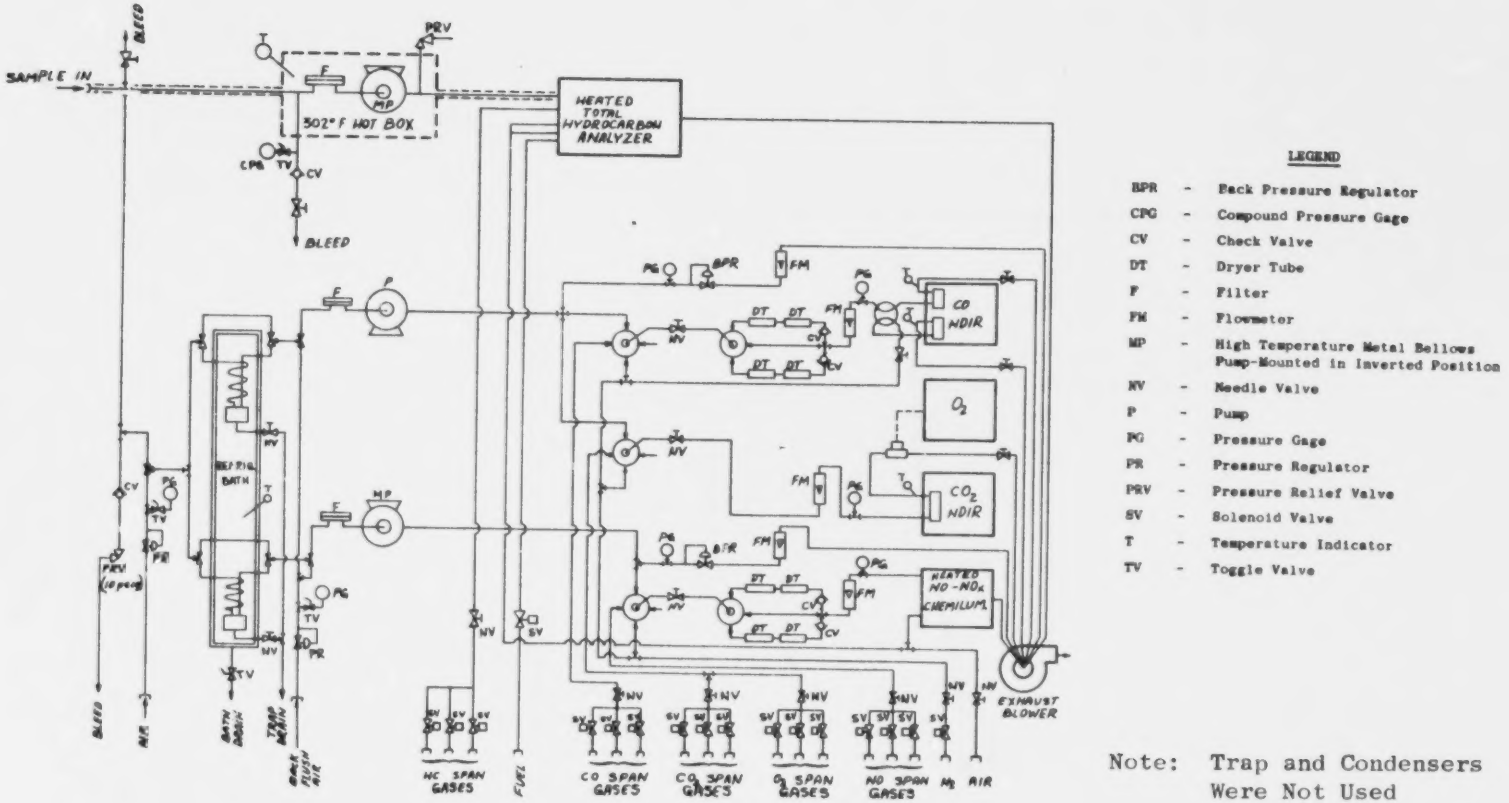


Figure 9. Sample Transit Times for Component Tests.



LEGEND

BPR	-	Back Pressure Regulator
CPG	-	Compound Pressure Gage
CV	-	Check Valve
DT	-	Dryer Tube
F	-	Filter
FM	-	Flowmeter
MP	-	High Temperature Metal Bellows Pump-Mounted in Inverted Position
NV	-	Needle Valve
P	-	Pump
PG	-	Pressure Gage
PR	-	Pressure Regulator
PRV	-	Pressure Relief Valve
SV	-	Solenoid Valve
T	-	Temperature Indicator
TV	-	Toggle Valve

Note: Trap and Condensers Were Not Used

Figure 10. General Electric On-Line Exhaust Emissions Analysis System, Flow Diagram.

Table 2. Span Gases for Gaseous Emissions Analyzers.

Pollutant	Range	Nominal Full Scale Reading	Calibration Span Gases
CO_2 (%)	3	3%	1.15, 2.48, 4.94, 8.03
	2	9%	
CO (ppm)	3	550 ppm	100, 240, 473, 1095
	2	1200 ppm	
HC* (ppm)	3	160 ppm	74.3, 143, 680, 1328
	4	800 ppm	
	5	1600 ppm	
NO_x (ppm)	3	80 ppm	28.7, 60.6, 174, 539
	4	200 ppm	
	5	800 ppm	

*Calibrated and reported as ppm of carbon.

Emission	Response Time, Seconds	
	Measured	Maximum Allowable *
CO_2	4.6	7
CO	5.8	7
HC	1.5	7
NO_x	5.0	9

*Reference 3

Ranges and deflections of all gaseous-emissions instruments are input directly to the 900-channel digital system, in the control room, where they are integrated with current combustor operating data. All emissions and operating data are printed out on paper tape and simultaneously transmitted to an on-line computer for automatic data reduction. Instrument deflections are also recorded continuously on strip-chart recorders to provide a permanent analog record of test results. Details of the data-reduction methods employed for this program are given in Section 4.3.

Smoke emissions were measured in this program using the standard General Electric filter-stain method; this is in conformance with the procedure in Reference 3. The system used is equipped with provisions for automatic switching and sample timing and is packaged into a portable console as shown in Figure 11. Nominal smoke spot densities of 0.013, 0.024, 0.036, and 0.048 pounds of sample per square inch of filter paper were obtained at each test point.

4.3 DATA REDUCTION METHODS

A flow chart for CFM56 combustor rig-test data reduction is presented in Figure 12. Except for the acquisition and reduction of smoke data, all data processing within this structure is handled automatically.

CO, CO_2, HC, and NO_x analyzers are calibrated prior to each test run, as described in Section 4.2. The calibration data (CALDATA) are input to a computer program (CALIB) that fits the electronic output of the emissions analyzers to the corresponding span-gas concentrations. The calibration data are fit to a function of the form

$$Y = \frac{(X - X_o)}{A + B\,(X - X_o)} \qquad (1)$$

where X is the analyzer output for gas concentration Y, X_o is the analyzer output with zero gas, and A and B are the general curve-fit constants. This function closely approximates the NDIR analyzer output nonlinearity with

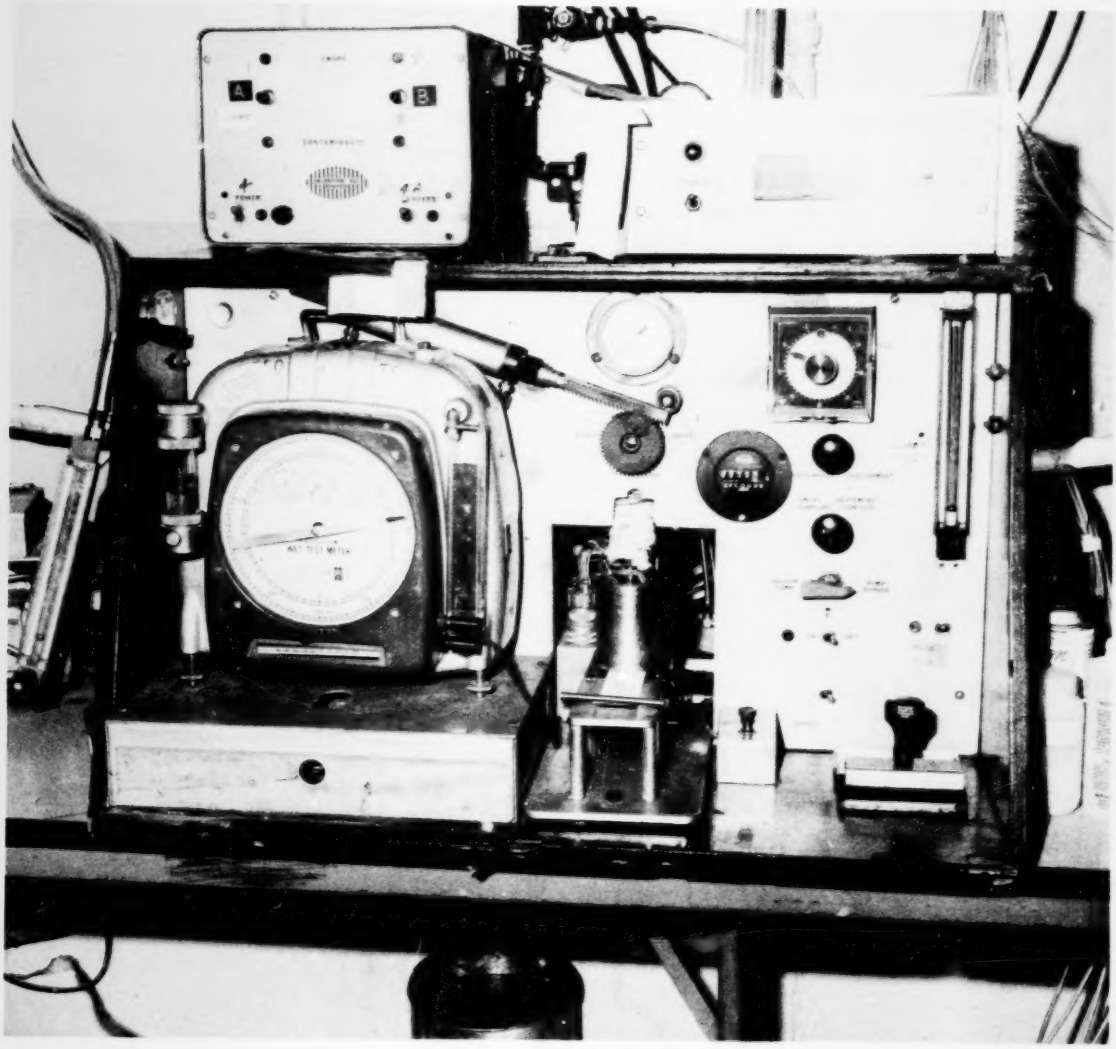


Figure 11. Portable Smoke Console.

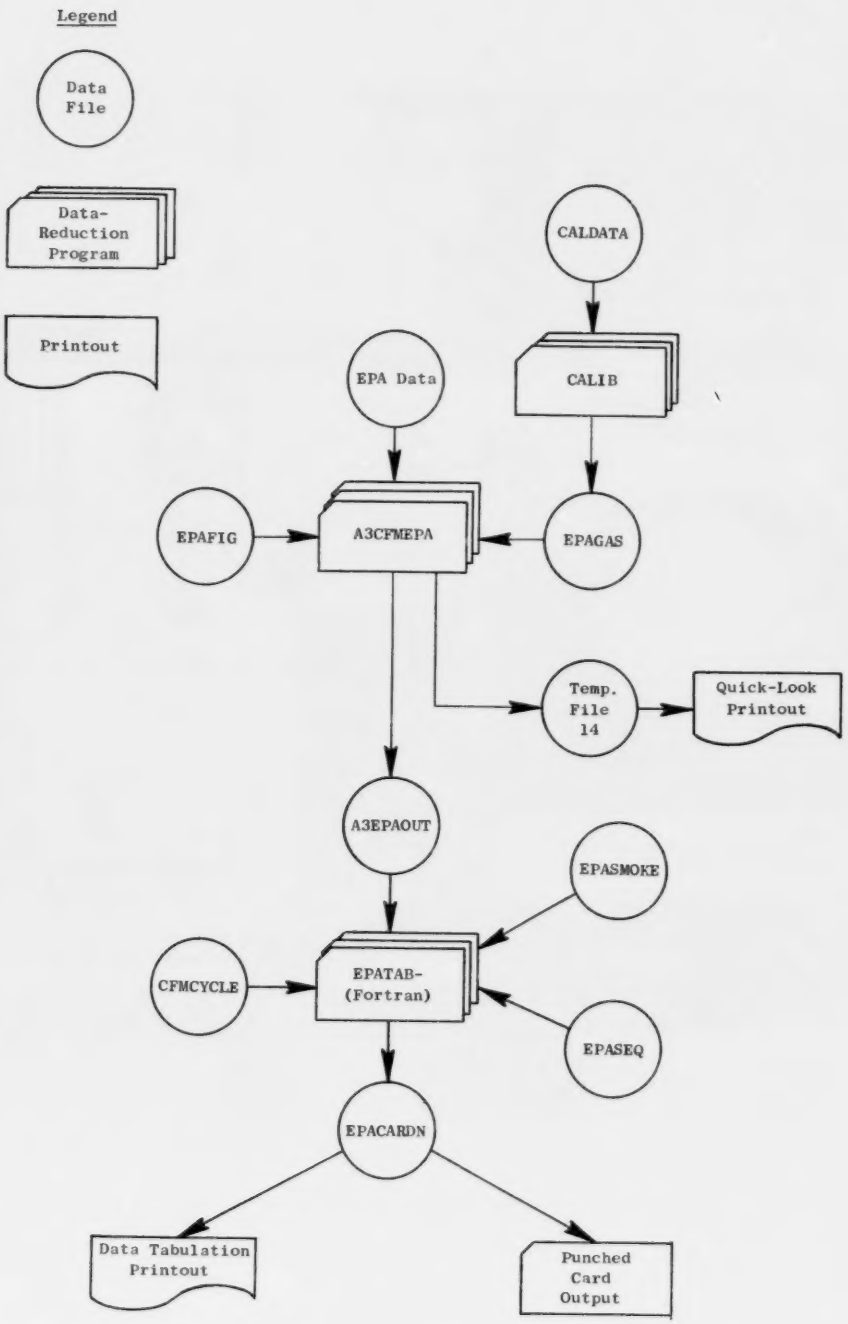


Figure 12. Data Reduction Flowpath for CFM56/EPA Combustor Rig Tests.

small negative values of B and conforms to the linear chemiluminescence and flame-ionization detector outputs with B = 0. This function has been shown to fit all analyzer output characteristics within 2% over the range of concentrations measured in CFM56 combustor rig tests. The constants A and B in the above expression are stored in a time-share computer system data file, EPAGAS, for use in on-line data reduction.

During the test, the computer data-reduction system is continually on line to provide reduced data as the operating points are run. When steady-state operation has been established at selected inlet conditions, the digital system is activated, and all pertinent operating and emissions data are scanned. As the scan proceeds, data are permanently recorded on paper tape and simultaneously transmitted to a time-share data file, EPADATA.

When the scan is completed, the EPADATA file is input, along with the gas-analyzer calibration data (EPAGAS) and a configuration (EPAFIG) describing the EPADATA file format, to the master data-reduction program (A3CFMEPA). The program converts digital system (millivolt) output into engineering units, averages multiple raw-data readings, calculates applicable combustor-operating parameters and emissions levels, and prints out these data in the form of a quick-look table. Reduced data are simultaneously added to another file, A3EPAOUT, which acumulates data from all test points for further processing. The quick-look printout is normally available before complete acquisition of smoke data for the selected test point; thus, the reduced operating and emissions data can be checked prior to setting subsequent test points.

A listing of parameters which appear in the quick-look printout and those which are transmitted to the A3EPAOUT file is presented in Table 3. A majority of these parameters are self-explanatory, but a few of the items require further clarification:

- The replication indicates the number of times that the subject test point has been run. Each point in the matrix was run at least twice, as discussed in Section 4.4.

- Combustor inlet flow function and reference velocity are computed based on inlet total pressure and temperature and total combustor airflow. Inlet flow function based on total combustor effective metering area is used to check combustor pressure drop. By General Electric convention, reference velocity is calculated based on casing cross-sectional area. This parameter is used to compare combustor-rig operating conditions with actual engine conditions.

- Two combustor inlet humidities are presented. The calculated humidity is the sum of cell inlet-air humidity plus additional humidity, due to water injection, as calculated from measured airflow and water injection rate. The measured value is the humidity measured at the inlet plenum. These values were generally in good agreement, as discussed in Section 4.5. The calculated humidity value is transmitted to the A3EPAOUT data file for further processing.

Table 3. Reduced Data Output.

Parameter	Recorded in	
	Quick Look	A3EPAOUT
Run	X	X
Rdg	X	X
Date	X	X
Point	X	X
Replication	X	X
Combustor Airflow	X	X
Main Fuel Flow	X	X
Verification Fuel Flow	X	
Flow Function ($W\sqrt{T}/PA$)	X	
Combustor Inlet Pressure	X	X
Combubustor Exit Pressure	X	
Combustor Pressure Drop	X	
Combustor Inlet Temperature	X	X
Combustor Exit Temperature	X	
Combustor Temperature Rise	X	
Reference Velocity	X	
Metered Fuel/Air Ratio	X	X
Upstream Humidity	X	
Water Injection Flow	X	
Inlet Humidity - Calculated	X	X
- Measured	X	
Sample Line Temperatures (10)	X	
Sample Line Pressures (5)	X	
Emissions		
Percent CO_2	X	X
ppm CO - Uncorrected	X	
ppm CO - Corrected	X	X
ppm HC	X	X
ppm NO_x	X	X
EICO - Uncorrected	X	
EICO - Corrected	X	X
EIHC	X	X
$EINO_x$	X	X
Sample Fuel/Air Ratio	X	X
Sample Combustion Efficiency	X	X

- Emissions indices are calculated using standard equations from SAE ARP 1256. The CO NDIR values are corrected for CO_2 and H_2O interference based on manufacturer's interference data. Corrections used are 1 ppm CO per percent CO_2 and 0.833 ppm CO per percent H_2O in the sample. $EINO_x$ and EIHC are presented as pounds of NO_2 per 1000 pounds of fuel and pounds of CH_4 per 1000 pounds of fuel, respectively. Combustion efficiency is calculated assuming that unburned hydrocarbons have the same heat of combustion per mole of carbon as the fuel used.

Smoke data are reduced and presented in accordance with methods specified in Reference 3. Following each run, smoke spots from each test point are analyzed with a reflection densitometer. Smoke number is converted to a sample flow spot density of 0.0230 pounds of exhaust gas per square inch of filter paper using a least-squares fit of smoke number versus the logarithm of sample flow density. Resulting smoke numbers are manually input to the EPASMOKE data file for further processing.

At the conclusion of the test program, the A3EPAOUT and EPASMOKE data files are input to the EPATAB computer program. This program formats the data in the reading sequence specified in the EPASEQ file, applies correction factors to convert emissions levels to actual engine-operating conditions specified in the CFMCYCLE file, and prints out the data both on punched cards and in an overall data tabulation. The punched cards obtained from this program were sent to Calspan Corporation for statistical analysis. The format and content of the data tabulation is discussed in Section 4.5.

4.4 RIG TEST POINT SCHEDULE

The rig tests involved measurement of emissions from a full-scale CFM56 combustor over a range of inlet-air humidities, a range of simulated engine-inlet-air temperatures, and a range of simulated engine-inlet pressures. The test conditions (specified in the contract) are listed in Table 4. As shown in this table, the rig tests covered a range of absolute humidity from 14 to 175 gr/lb, a range of simulated engine-inlet temperature from 19 to 105° F, and a range of simulated engine-inlet pressure from 25.98 to 32.28 inches of mercury. Figure 13 shows the humidity/temperature relationship for the test conditions and the range of relative humidity of the test.

For each of the 22 test points listed in Table 4, emissions measurements were planned for five simulated engine power settings (idle, 1.5 idle, approach, climb out, and takeoff) for a total of 110 test points. Each test point was to have been run twice for a total of 220 test readings. During the actual testing, three test conditions could not be reached due to limitations on the air-heater temperature; thus, 214 test readings were finally obtained.

The simulated engine conditions for the rig tests were determined from the CFM56 computer cycle as configured for the engine on which the emissions tests were to be run (Engine 502-005/2). This required a total of 110 separate cycle

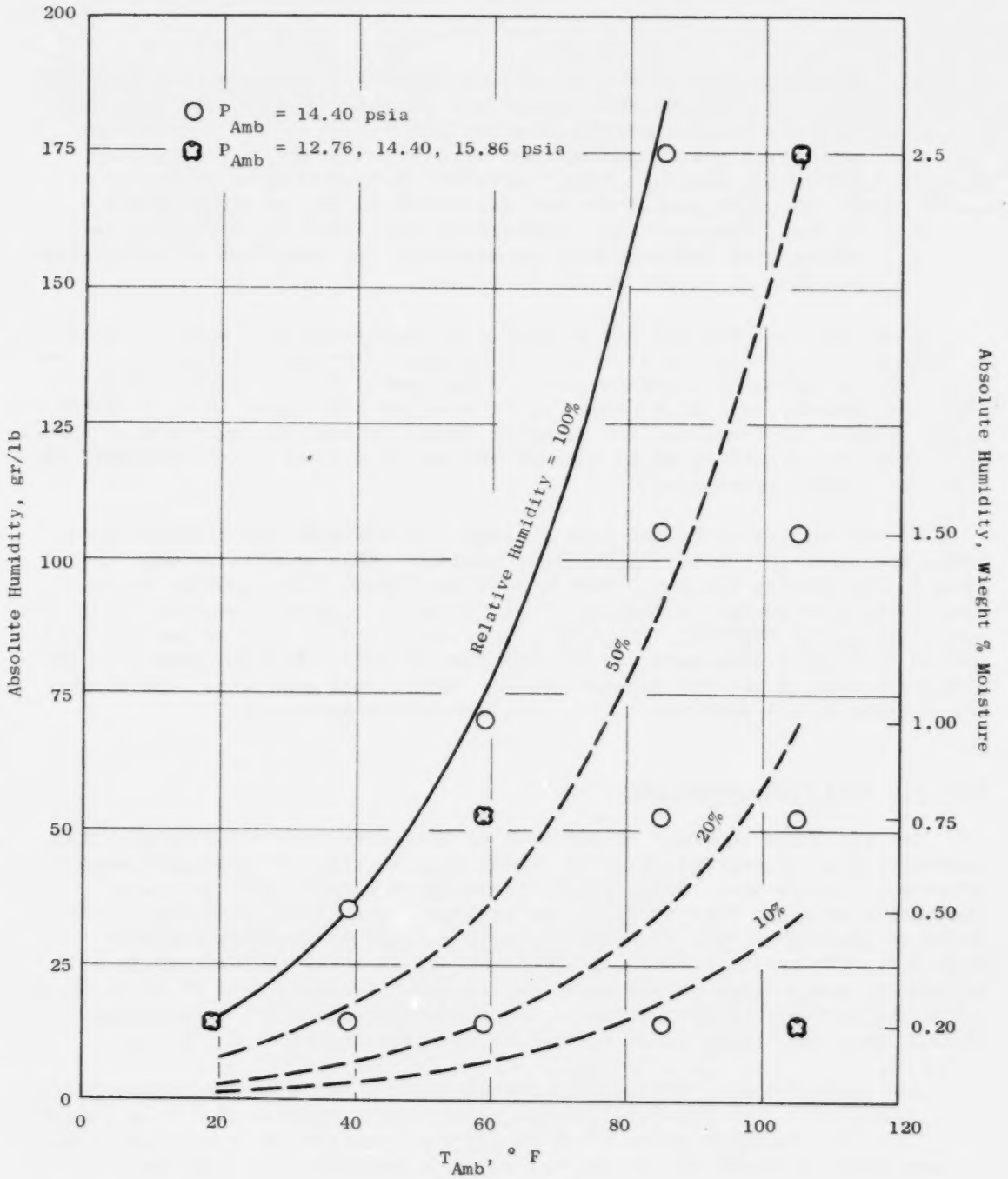


Figure 13. Temperature/Humidity Relationship of Test Point Schedule.

Table 4. CFM56 Rig Test Matrix.

Test Point	Temperature		Humidity		Pressure	
	°C	°F	Grams H_2O Per Kilogram Air	Grains H_2O Per Pound Air	Held constant as specified in the United States Standard Atmosphere 1962 for the Test Cell Altitude	
					kPa	in.-Hg
1	-7	19	2	14	109.32	32.28
2	4	39	2	14	109.32	32.28
3	15	59	2	14	109.32	32.28
4	29.5	85	2	14	109.32	32.28
5	40	105	2	14	88	25.98
6	4	39	5	35	88	25.98
7	15	59	7.5	52.5	88	25.98
8	29.5	85	7.5	52.5	88	25.98
9	40.5	105	7.5	52.5	88	25.98
10	15	59	10	70		
11	29.5	85	15	105		
12	40.5	105	15	105		
13	29.5	85	25	175		
14	40.5	105	25	175		
15	-7	19	2	14		
16	15	59	7.5	52.5		
17	40.5	105	2	14		
18	40.5	105	25	175		
19	-7	19	2	14		
20	15	59	7.5	52.5		
21	40.5	105	2	14		
22	40.5	105	25	175		

- Twenty-two test points (given above).
- Five power settings - idle, 1-1/2 times idle, approach, climb out, takeoff.
- Two replications of each test point.
- Two-hundred and twenty total measurements (22 x 5 x 2 = 220).

calculations at the various specified conditions of power and ambient temperature, pressure, and humidity. The idle points were calculated for constant corrected core speed to give 6% thrust on a standard day. This simulates the operation of the engine control system (which maintains constant corrected speed at idle). Similarly, the 1.5-times-idle points were calculated for constant corrected core speed to give 9% thrust on a standard day. The approach, climb-out, and takeoff power conditions (30%, 85%, and 100% power respectively) were calculated for constant corrected thrust, as specified by the EPA measurement procedure, based on engine takeoff thrust of 22,000 lbf. Selected simulated engine conditions from these cycle calculations are given in Table 5 along with the results of the combustor-rig tests.

Combustor conditions calculated from the cycle data could be accurately simulated in Cell A3 except for the takeoff and climb-out conditions; these exceeded the pressure capability of the system. These two simulated engine-power conditions were therefore run at combustor inlet pressures somewhat lower than the corresponding engine pressure. In operating at reduced pressure, the airflow is reduced in the same proportion as the pressure in order to maintain the same reference velocity, and the fuel flow is reduced in the same proportion in order to maintain the same combustor fuel/air ratio and temperature rise. Thus, all important combustor parameters except pressure are accurately simulated at the two highest power conditions.

Since statistical analyses of the rig-test data were to be performed, it was desirable that the data be obtained in a random fashion to avoid any biasing. This was done insofar as practical; in particular, the replicate data were always obtained with test points intervening. Expedient operation of the test facility, however, precluded completely random acquisition of test data. For example, data could be obtained most rapidly if test points were run in the order of increasing temperature and pressure. In addition, on some occasions, high ambient humidity precluded the "driest" test points (14 gr/lb). Consequently the driest test points were generally run in a group.

4.5 COMBUSTOR RIG TEST DATA

The combustor rig-test data were obtained in a series of nine separate tests in the period November 19, 1976 to December 15, 1976. In these tests, emissions levels of CO, HC, NO_x, and smoke were measured in the test rig with combustor inlet pressure, temperature, fuel flow, airflow, and humidity simulating conditions in the actual engine when operating at the specified power levels and ambient conditions of temperature, pressure, and humidity.

The CFM56 combustor rig test data are presented in Appendix A. Each page has four categories of data. The data tabulated under Simulated Engine Conditions include the EPA specified engine power level, simulated ambient conditions for the particular test point, and engine parameters calculated using the appropriate engine cycle as discussed in a previous section of this report. The Actual Rig Conditions are the measured values and were intended to be the same as the Simulated Engine Conditions. The third group of data is

Table 5. Comparison Between Measured and Calculated Inlet Humidity.

Run 8, December 13, 1976

Humidity, gr/lb dry air					Humidity, gr/lb dry air				
Rdg	Initial	Water Injected	Sum	Measured Inlet	Rdg	Initial	Water Injected	Sum	Measured Inlet
164	10.4	0	10.4	11.1	190	12.6	0	12.6	12.8
165	11.3	0	11.3	11.4	191	12.0	39.5	51.5	52.0
166	9.7	42.9	52.6	52.2	192	11.5	0	11.5	12.6
167	8.8	94.1	102.9	100.7	193	13.1	39.5	52.6	52.3
168	9.7	43.0	52.7	53.4	194	10.3	158.2	168.5	160.7
169	10.4	95.2	105.6	101.4	195	12.1	0	12.1	13.1
170	10.7	166.4	177.1	169.2	196	12.2	0	12.2	12.6
171	9.9	41.7	51.6	52.6	197	12.2	41.3	53.5	54.9
172	11.6	0	11.6	11.0	198	14.3	163.7	178.0	171.3
173	9.6	94.8	104.4	101.4	199	13.7	0	13.7	14.8
174	9.5	164.2	173.7	167.7	200	12.9	40.9	53.8	53.7
175	12.1	0	12.1	10.8	201	13.9	93.9	107.9	105.6
176	10.8	42.3	53.1	53.1	202	13.7	0	13.7	14.8
177	10.1	96.7	106.8	104.1	203	16.1	39.5	55.6	52.8
178	11.1	161.3	172.4	168.0	204	12.1	91.1	103.2	101.0
179	11.5	58.8	70.3	69.4	205	13.0	162.8	175.8	170.1
180	11.5	40.0	51.5	51.3	206	13.5	39.1	52.6	52.2
181	10.0	0	10.0	12.0	207	12.3	57.1	69.3	69.1
182	13.4	24.9	38.3	36.8	208	13.3	21.3	34.7	35.6
183	11.8	0	11.8	12.1	209	13.2	0	13.2	13.9
184	10.9	0	10.9	12.6	210	13.3	0	13.3	14.1
185	12.6	41.9	54.5	53.4	211	13.3	0	13.3	14.6
186	12.2	56.8	69.0	68.2	212	13.5	159.4	172.9	168.6
187	11 9	22.3	34.1	35.5	213	12.9	0	12.9	16.5
188	12.9	0	12.9	12.7	214	13.3	39.9	53.2	56.7
189	12.1	0	12.1	12.3					

measured emissions. The fourth group of data is emissions values corrected to the simulated engine conditions. These corrected data were used during the test program to allow comparison between high-power (85 and 100% of rated thrust) emissions levels, measured in the reduced-pressure rig tests, with levels obtained in previous engine tests. These data were also used to account for scatter due to slight pressure variations when comparing data obtained in replications of a given test point. For these corrections, only a pressure effect on NO_x and smoke is considered (a correction for the effect of pressure on CO is also considered in a later section of this report, but this correction was not included in the corrected data in Appendix A).

For the corrections in Appendix A, the NO_x emission index is taken to be proportional to the 0.37 power of the pressure, and the smoke number is taken to be proportional to the 1.5 power of pressure. These correction factors were derived from previous correlation studies on similar CFM56 combustors. It should be noted that these corrected data were used only as a means of data validation during the test program. Only the uncorrected data were used to derive the correction factors given in References 1 and 2.

Of the planned 110 different test points, three could not be obtained due to limitations on the air-heater temperature. These were at simulated takeoff conditions at 105° F ambient temperature and 175 gr/lb humidity and were well outside the operating limits of the CFM56. Thus, instead of the planned 220 readings (2 readings to each of 110 test conditions), reliable data were obtained for 214 readings.

The combustor inlet humidity-control system functioned quite well after the correction of some operational problems in the early test runs. As explained previously, initial air humidity is measured by the first hygrometer, and the total inlet humidity is calculated from this measurement along with the water-injection rate and the inlet airflow rate. The total inlet humidity is also directly measured by a second hygrometer at the inlet to the test combustor. Agreement between the calculated and measured humidity indicates that the injected water is completely vaporized and mixed with the inlet air before entering the combustor. Table 5 lists the comparison between calculated and directly measured humidity for all data points for Run 8. This particular run occurred late in the test series; excellent agreement between the two values may be noted.

4.6 CFM56 RIG TEST DATA CORRELATION

The rig-test data presented in Appendix A, along with a considerable quantity of both rig-test and engine-test data obtained from various sources by the EPA, has been statistically analyzed in detail by the Calspan Corporation (Reference 1) under contract to the EPA. Results of this study have also been summarized in an ASME paper (Reference 2). In that study, correction factors were derived based on the following choices:

1. Use of empirical rather than theoretical correction factors.

2. Use of combustor inlet conditions rather than ambient conditions for correlating variables.

3. Use of simple rather than complex model structure.

With this basic approach, correction factors were derived by Calspan as functions of only T_3 for CO and HC and as functions of T_3 and humidity for NO_x. Basically, this amounts to evaluating the emission index (EI) at constant corrected thrust by correcting CO and HC to the reference value of T_3 at that thrust, or to the reference value of T_3 and humidity in the case of NO_x. It should be noted that this method does not necessarily deny an explicit dependence of EI on P_3, fuel/air ratio, or other variables but only assumes that the difference between the actual and the reference value of these other variables is small enough to have negligible effect on the EI. Stated another way, the method assumes that when changes in combustor conditions at constant corrected thrust are due solely to changes in ambient conditions, the corresponding change in EI is adequately predicted (for CO and HC) by the corresponding change in T_3 or (for NO_x) by the corresponding change in T_3 and humidity.

A method which has been successfully used at GE is similar to the Calspan-EPA procedure in that it is based on combustor inlet conditions, is empirical, and is relatively simple. It is different from that procedure in that it contains provisions for an explicit dependence of EI on P_3 for CO, HC, and NO_x. The dependence of NO_x on humidity is the same in this GE procedure as in the Calspan-EPA method.

To demonstrate the explicit effect of P_3 on CO emission index for the CFM56 rig-test data reported here, the idle and 1.5 idle data of Appendix A are plotted in Figure 14. In this plot, EICO is plotted against T_3 for the six different values of P_3 between 43.3 and 70.5 psia. All data in this figure are at the lowest humidity level (about 14 gr/lb). It is obvious in this plot that there is a definite inverse effect of pressure on EICO; that is, EICO decreases with increasing P_3. If one assumes that EICO varies as some power of P_3, the power can be determined from the slope of the ln-ln plot as shown in Figure 15, where the natural logarithm of EICO is plotted against the natural logarithm of P_3. A linear fit by the method of least squares gives a pressure exponent of -1.48. In further calculations, this value is rounded to -1.5. This value is in good agreement with the pressure exponent of -1.46 which was reported in Appendix C of Reference 1. It should be noted that combustor inlet pressure (P_3) at a given power level varies in proportion to ambient pressure and that combustor inlet temperature and fuel/air ratio are not significantly affected by changes in ambient pressure. Therefore, as indicated in Reference 1, this pressure exponent yields corrections of less than $\pm 5\%$ for a typical range of ambient pressures encountered during testing at sea level (29.92 $\pm$1 in. of Hg). For tests conducted on a standard day at an elevation of 1000 feet above sea level, the indicated pressure correction is about -5%.

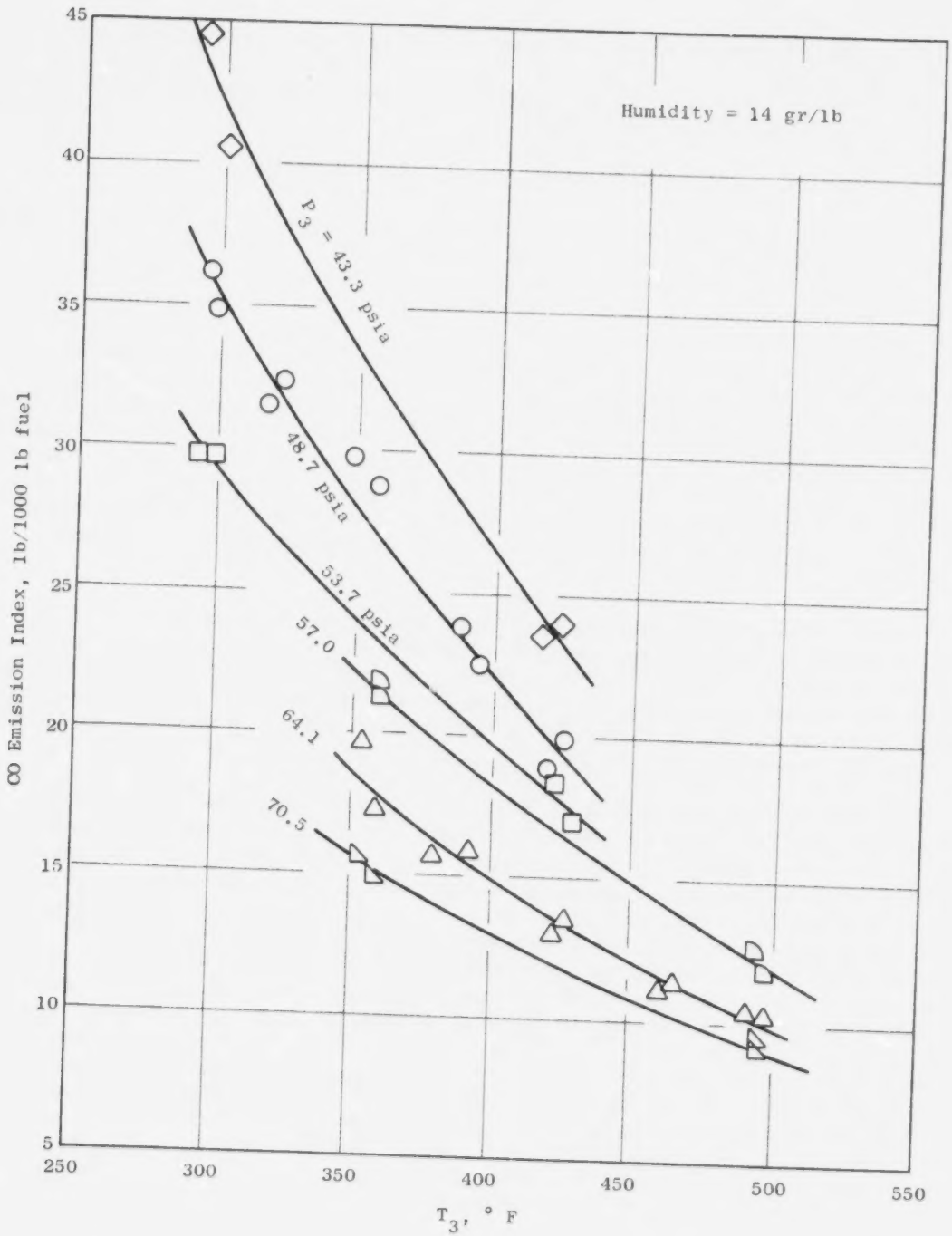


Figure 14. Effect of P_3 on CO Emission Index for Idle and 1.5 Idle Rig Test Data.

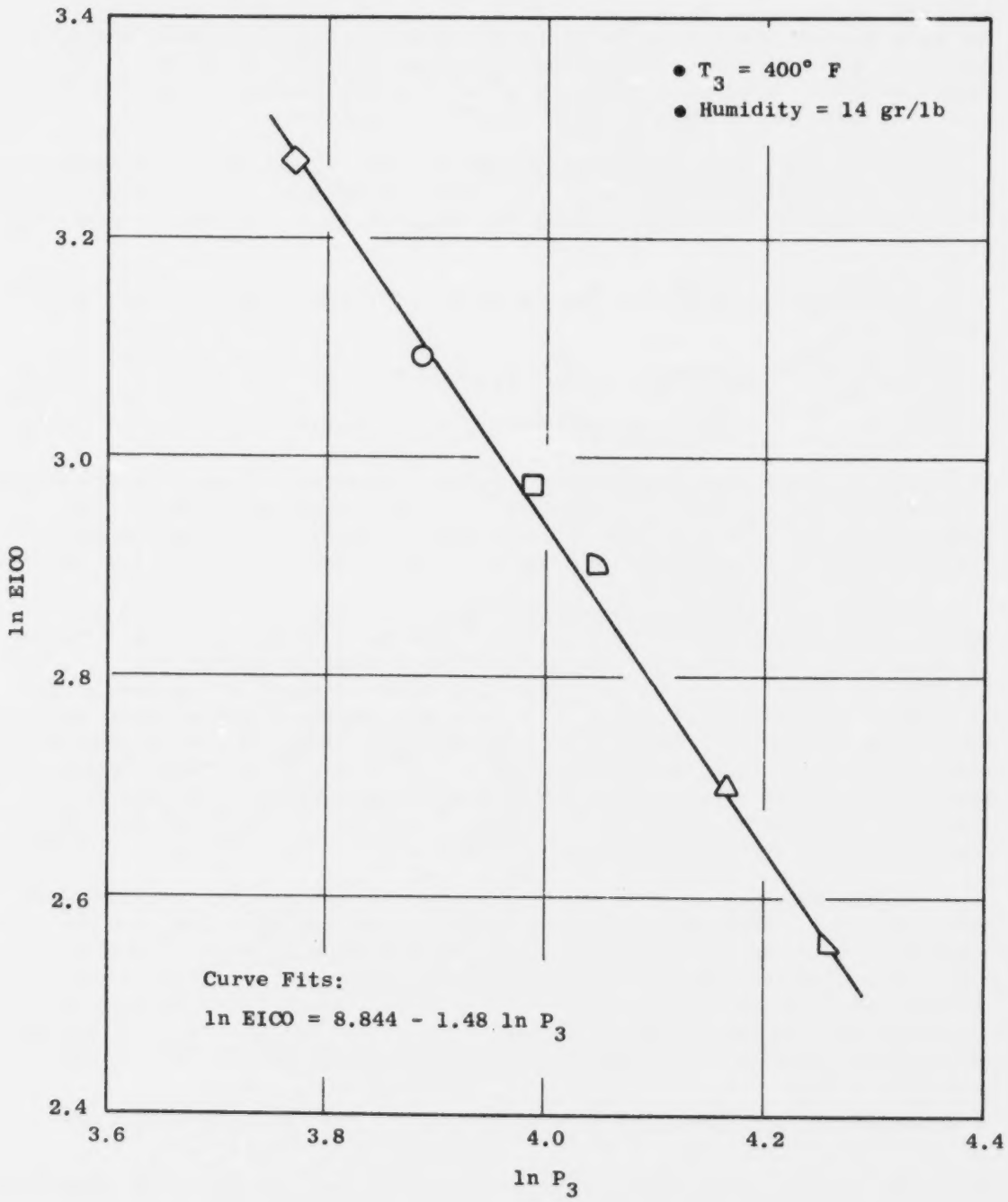


Figure 15. Evaluation of Pressure Exponent for CO Emission Index. (Crossplot of Figure 14 Data at 400° F)

A similar treatment of the HC data yields a pressure exponent of -2.5, although the pressure effect on HC is much less obvious than on CO due to the much greater scatter in the HC data. This scatter in HC data, which is typically quite variable, is much more apparent here due to the very low values of EIHC. A pressure exponent of -2.5 yields correction factors of less than ±10% over a typical range of ambient pressure.

Similar plots have been made of EICO and EIHC versus T_3, at constant pressure, for various humidity levels. These plots show no significant effect of humidity on CO and HC over the range of humidity levels investigated.

This effect of P_3 may be used to correct the CFM56 rig-test data as follows:

$$\text{Corrected EICO} = \text{EICO} \; (P_3/P_3 \text{ Ref})^{1.5} \qquad (2)$$

$$\text{Corrected EIHC} = \text{EIHC} \; (P_3/P_3 \text{ Ref})^{2.5} \qquad (3)$$

It should be noted that the reference value of pressure, P_3 Ref, is evaluated at reference-day conditions and the T_3 of the emission measurement. In subsequent calculations P_3 Ref is taken from the CFM56 Certification Cycle (1976). This is the engine reference performance data used at GE for the CFM56.

Figure 16 shows the uncorrected EICO plotted against T_3 for all of the CFM56 combustor rig data. This plot includes the data in Figure 14. Figure 17 shows EICO, corrected for P_3 per Equation 2, plotted against T_3. Similar uncorrected and corrected data for EIHC are shown in Figures 18 and 19. These two latter plots show only data for the three lowest power levels because at 85% and 100% power EIHC is essentially zero. As may be seen by comparison of corrected and uncorrected CO and HC levels in these figures, the application of the pressure correction considerably reduced the spread in these rig-test data. However, as indicated previously, much less data spread due to pressure variation would be observed under typical engine-test conditions.

For the NO_x data, both a pressure correction and a humidity correction were developed. Previous studies at GE have indicated that $EINO_x$ varies in proportion to P_3 to the 0.37 power, and in proportion to [exp -18.8 × H] (where H is absolute ambient humidity in grains per pound). Both these factors are in excellent agreement with values obtained in the Calspan-EPA study, where 0.34 for the pressure exponent and -19 for the humidity exponent were quoted (Reference 2). Application of the GE-derived factors results in:

$$\text{Corrected EINO}_x = \text{EINO}_x \; (P_3 \text{ Ref}/P_3)^{0.37} \exp - 18.8 \; (44 - \text{Humidity})/7000 \qquad (4)$$

where the humidity term is referred to 44 gr/lb, the "reference-day condition" defined by the EPA (Reference 3). Figures 20 and 21 show the uncorrected and corrected $EINO_x$ versus T_3 for the CFM56 combustor rig-test data. As with the CO and HC data, application of the NO_x correction factor causes the data to "collapse" quite well on the T_3 plot.

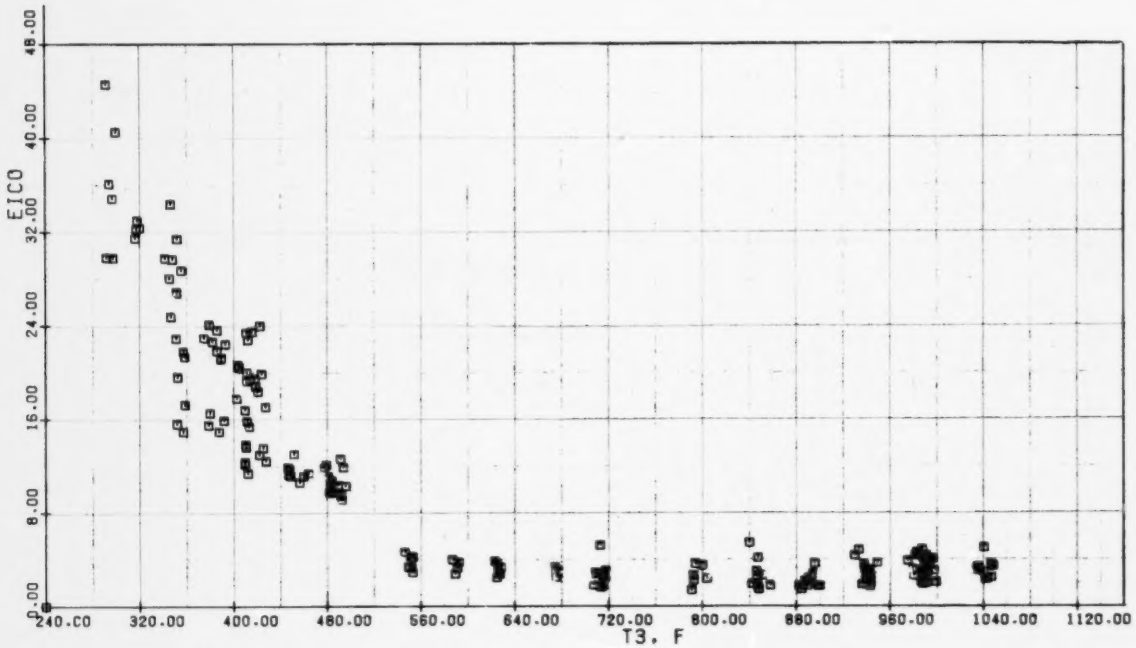


Figure 16. CFM56/EPA EICO Vs. T_3.

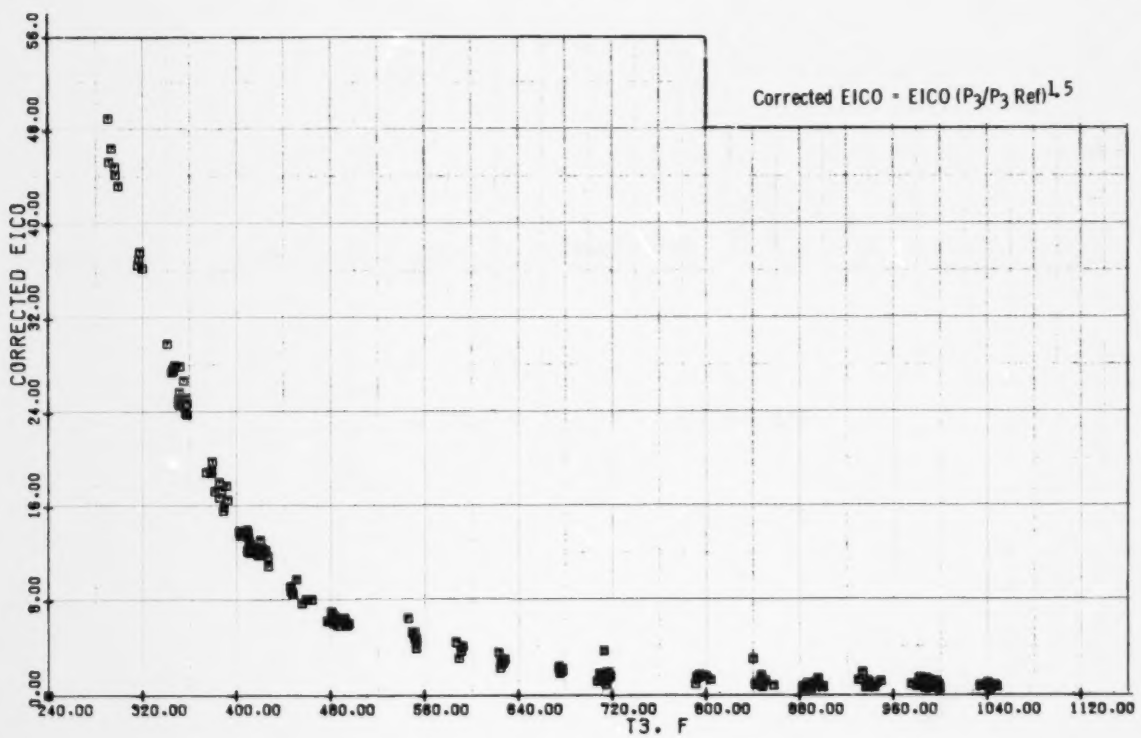


Figure 17. CFM56/EPA EICO Vs. T_3 (EICO Corrected for Pressure).

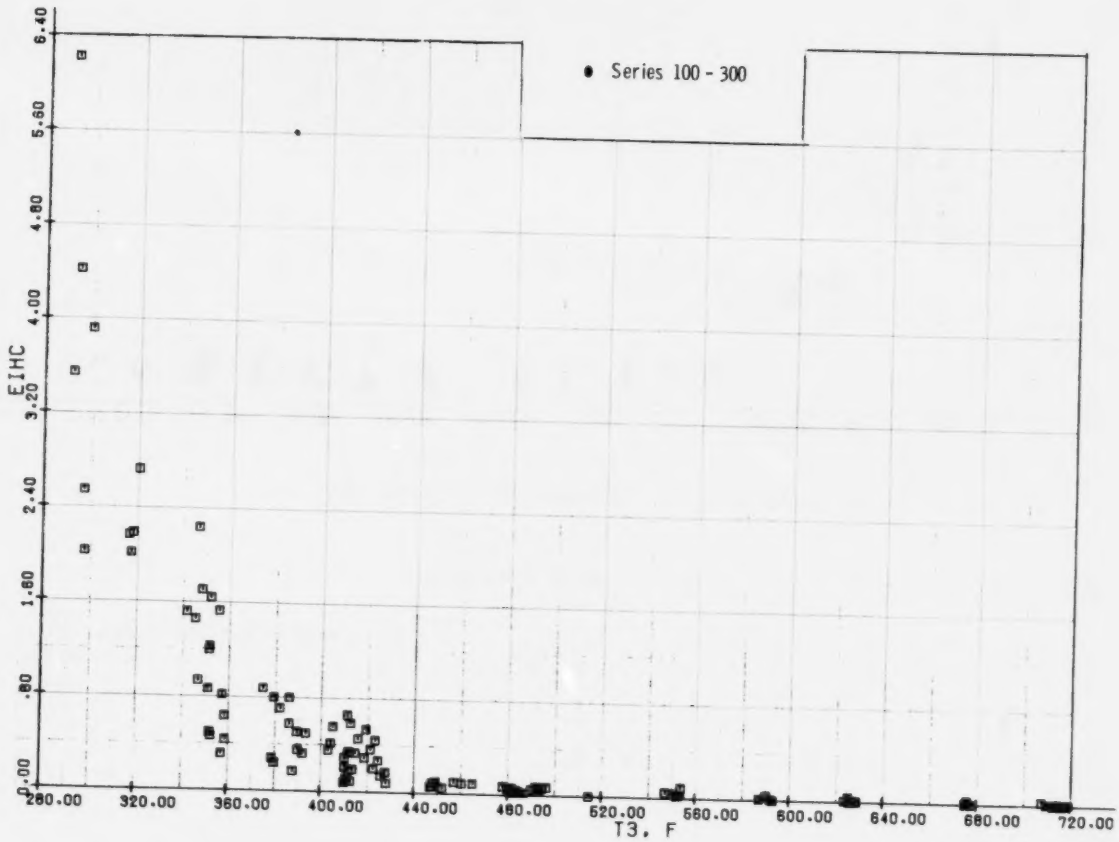


Figure 18. CFM56/EPA EIHC Vs. T_3.

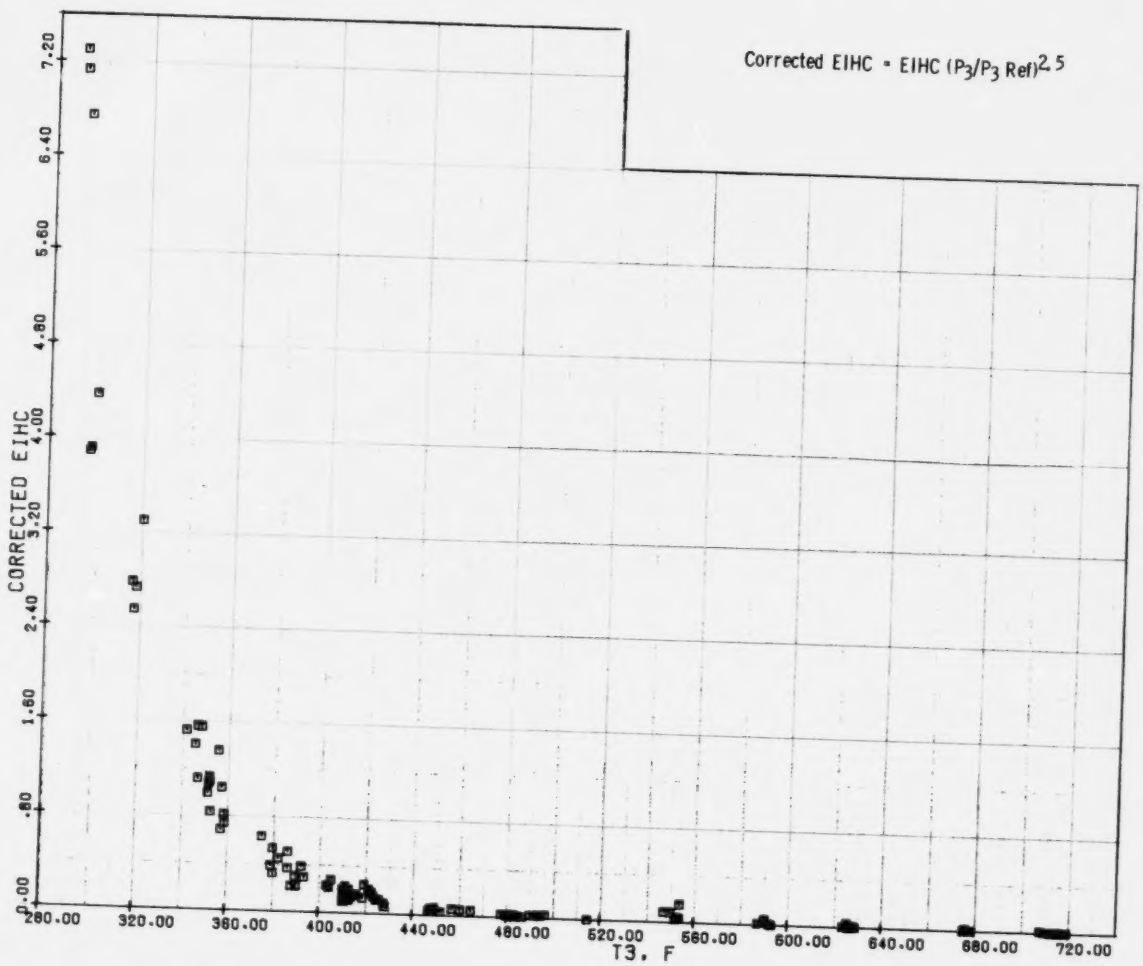


Figure 19. CFM56/EPA EIHC Vs. T_3 (EIHC Corrected for Pressure).

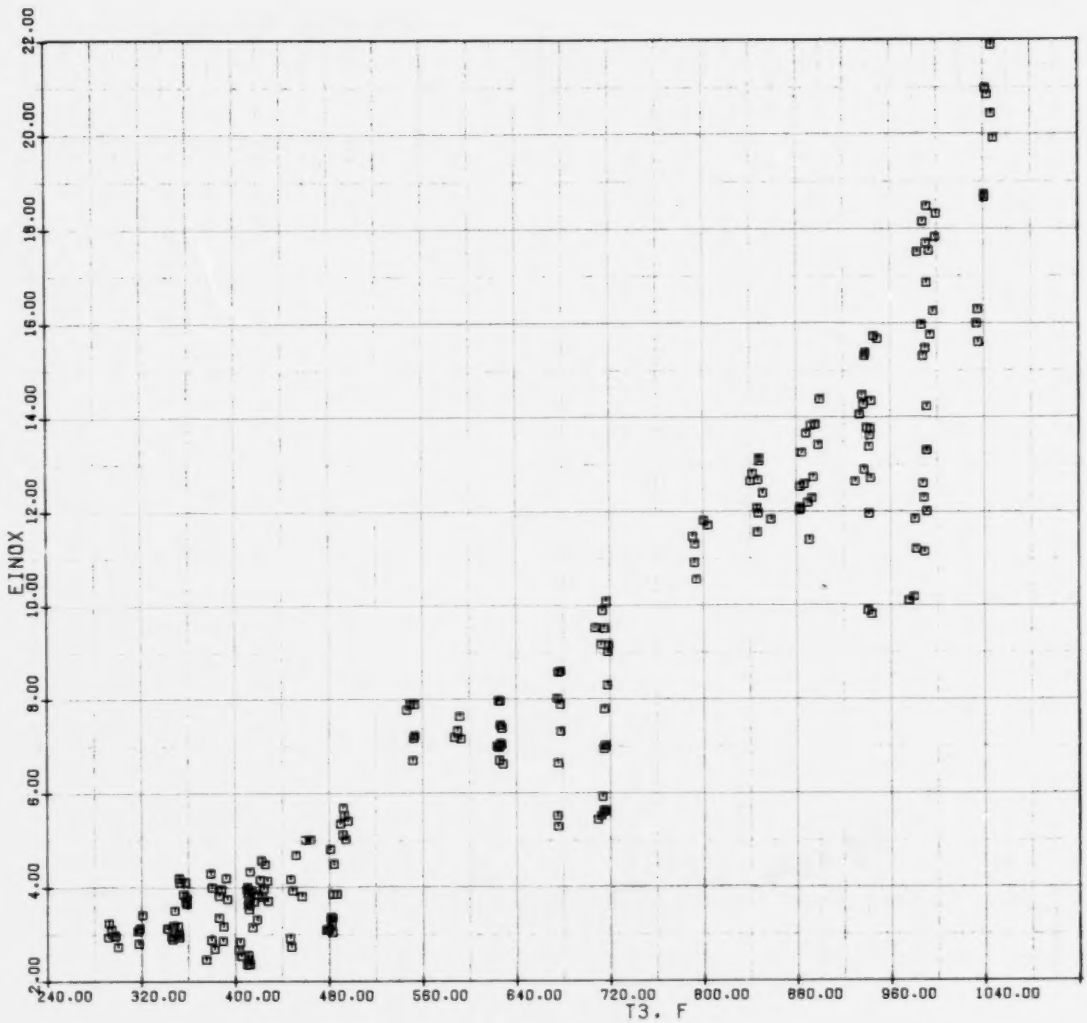


Figure 20. CFM56/EPA $EINO_x$ Vs. T_3.

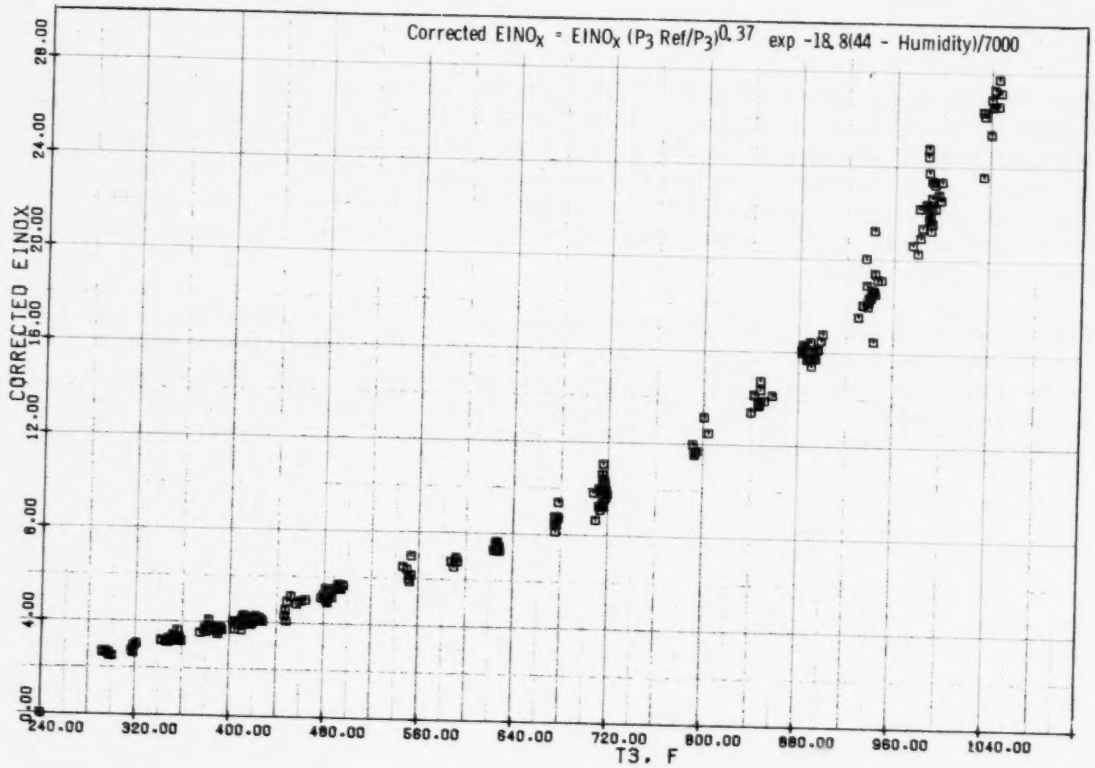


Figure 21. CFM56 Corrected $EINO_x$ Vs. T_3.

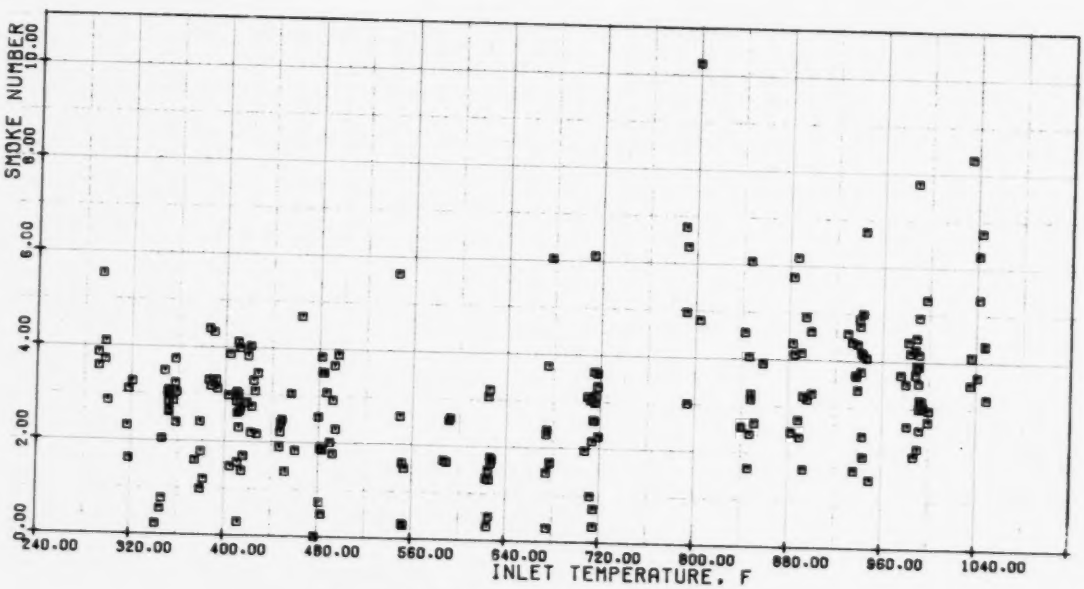


Figure 22. CFM56 Rig Smoke Data.

The inclusion of the pressure correction factor in the data analyses presented here is not meant to imply that it is necessary in all cases or that the improvement in data precision is worth the increase in complexity. It seems obvious that, in cases where the test pressure is much different than the actual engine pressure, a correction is essential. Such is the case in the current series of rig tests, where the rig-test pressure was only about half the true engine pressure.

Figure 22 is a plot of uncorrected smoke number against combustor inlet temperature for the rig-test data. These data are at very low smoke number (generally less than 7), and there is considerable scatter. No significant effort has been made to correlate these smoke data. Analyses of similar data at GE have shown a pressure exponent of about 1.5.

5.0 CFM56 ENGINE EMISSIONS TESTS

Verification of the rig-test data involved emissions tests on a full-scale CFM56 engine. These tests were run under uncontrolled ambient conditions. The tests were scheduled to obtain as wide a range of ambient conditions as practicable.

Six separate tests were executed; each test consisted of the same five engine power settings as the rig tests (idle, 1.5 idle, 30%, 85%, and 100% of nominal takeoff power). This section is a discussion of the engine test facility, instrumentation, and results of the engine tests.

5.1 ENGINE TEST FACILITY

The CFM56 engine tests were conducted at GE-Evendale in Development Engine Test Cell 6. This cell is equipped with the extensive services required for testing of development engines. The central Instrumentation Data Room (IDR) serves all development test cells and is located one floor below the test cell area.

Cell 6 was designed specifically for the development testing of large turbofan engines at sea-level-static conditions. The general arrangement of the cell is shown in Figure 23. Air enters the cell from an inlet mounted on the roof. An array of turning vanes provides uniform, horizontal flow to the engine. The engine exhausts into an augmentor, where the exhaust is acoustically treated, and exits into the atmosphere through a vertical stack. The augmentor pumps secondary air that flows around the engine and provides external cooling. The engine is suspended from a thrust-measuring frame through a flight-type pylon and engine fan-duct cowling. The engine centerline is nominally 10 feet from the floor.

The engine is operated from an acoustically isolated control room adjacent to the test cell. The exhaust-gas-analysis equipment was located in the mezzanine area adjacent to the test cell and approximately in-line with the sampling rake.

The engine was equipped with the normal development-test instrumentation needed to properly monitor engine performance. Engine operating data were recorded on the Automatic Data Handling (ADH) system. These data are recorded on magnetic tape, computed, and printed out by the equipment located in the IDR.

5.2 EMISSIONS SAMPLING AND ANLYSIS SYSTEM

Exhaust samples were obtained through a remotely operated, rotatable-rake system. This system was designed for and previously used on the NASA/GE Experimental Clean Combustor Program (Reference 4). A sketch of the rake system is shown in Figure 24. The main ring is 8 feet in diameter and is mounted to the framework by a system of rollers. Eight sampling rakes are attached to

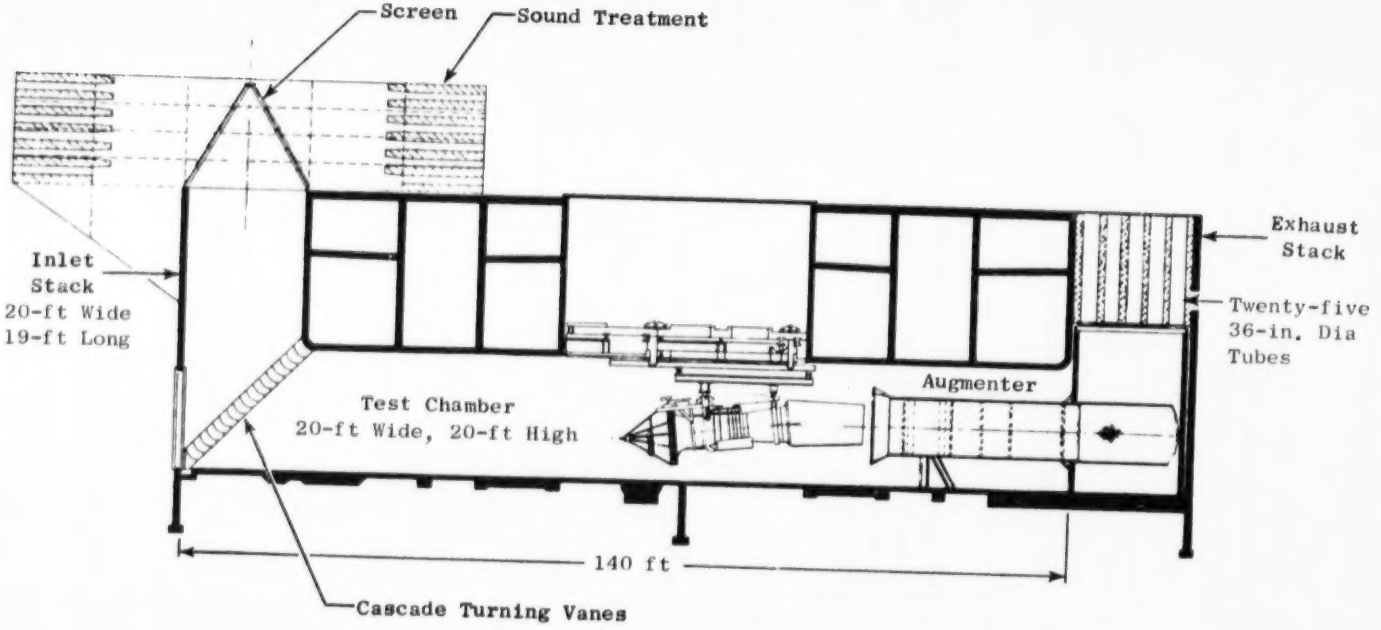


Figure 23. Development Engine Test Cell Cross Section.

Screw Drives Nut to Rotate Counterclockwise to 0° Position.
Rakes 1, 3, 5, 7 are Manifolded to Give Sample "A".
Rakes 2,4, 6, 8 are Manifolded to Give Sample "B".

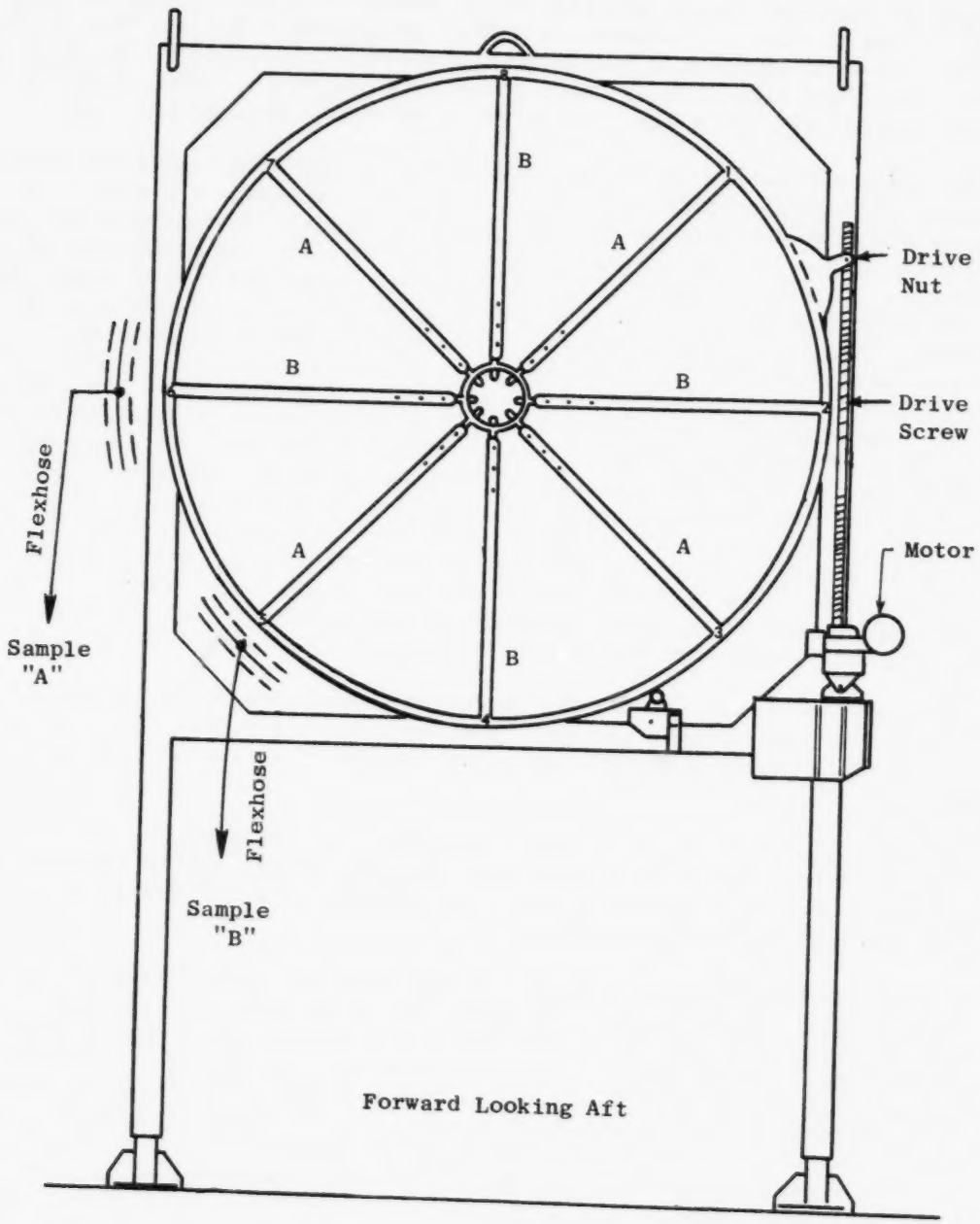


Figure 24. Rake System Shown at 45° Position.

the ring. Rotation of the entire ring assembly through 45° is accomplished with the rotating screw and traveling nut.

Each of the eight rakes contains three sample orifices; alternate rakes are manifolded to give two separate samples, designated A and B. This forms a double-cruciform sampling arrangement with 12 orifices in each cruciform and with one cruciform displaced 45° with respect to the other. Rake rotation is remotely controlled, and a digital indicator shows the angular position.

The CFM56 engine (Serial Number 502-005/2) on which the emissions measurements were made contains a confluent core- and fan-exhaust system. In this configuration, the core engine exhaust nozzle is located 34.5 inches upstream of the main nozzle. Since the sampling rake is located just downstream of the main nozzle, the exhaust profile at the sampling plane consists of a hot region near the engine centerline (the core engine exhaust) surrounded by a relatively cool region (the fan stream). There is a relatively narrow transition region where some mixing of the two streams occurs. Previous engine-test data (on a different CFM56 engine with a confluent exhaust system) had shown that the mixing region is located between about 10 and 13 inches radially from the engine centerline at the exhaust plane. Based on this information, the sampling pattern shown in Figure 25 was selected so that Rake A would sample only from the core stream and Rake B would sample to approximately the outer edge of the mixing region. The sample from Rake A would thus be expected to show a fuel/air ratio in agreement with the core engine fuel/air ratio; Rake B sample fuel/air ratio would be somewhat lower than that of the core engine but considerably higher than the overall-engine (including fan stream) fuel/air ratio. The area sampled by Rake B was selected to include all the fuel flow.

It should be noted that the EPA procedure (Reference 3) is not specific about how a confluent engine should be sampled; it only states that the sample must be representtive - as indicated by the following quotation from that document:

> "87.63 (1)(ii)(e) In all cases, the probe shall be designed to obtain a representative sample over the area of the entire exhaust nozzle, on both mixed fan engines and nonmixed fan engines as well as turbojet and turboprop engines."

If the sampling pattern were selected to reproduce the overall engine fuel/air ratio (including fan air), it is clear that a considerable portion of the air must be drawn from the fan stream for a high bypass ratio engine such as the CFM56 (6 to 1 bypass ratio). This would dilute the sample excessively, giving typical fuel/air ratios at takeoff power of about 0.003 rather than 0.02 (the CFM56 core engine fuel/air ratio). This dilution is so high that ambient concentration levels become appreciable compared to the measured levels. For example, CO_2 levels of about 0.6% would be measured as compared to the typical ambient level of 0.03%. If not considered in the calculations, this would cause an error in measured fuel/air ratio of about 5%. Based on this reasoning, and with the concurrence of the EPA project officer, the sampling pattern shown in Figure 25 was selected.

- Indicator Position Shown is 0°
- Rotation is Clockwise (Aft Looking Forward) 45°

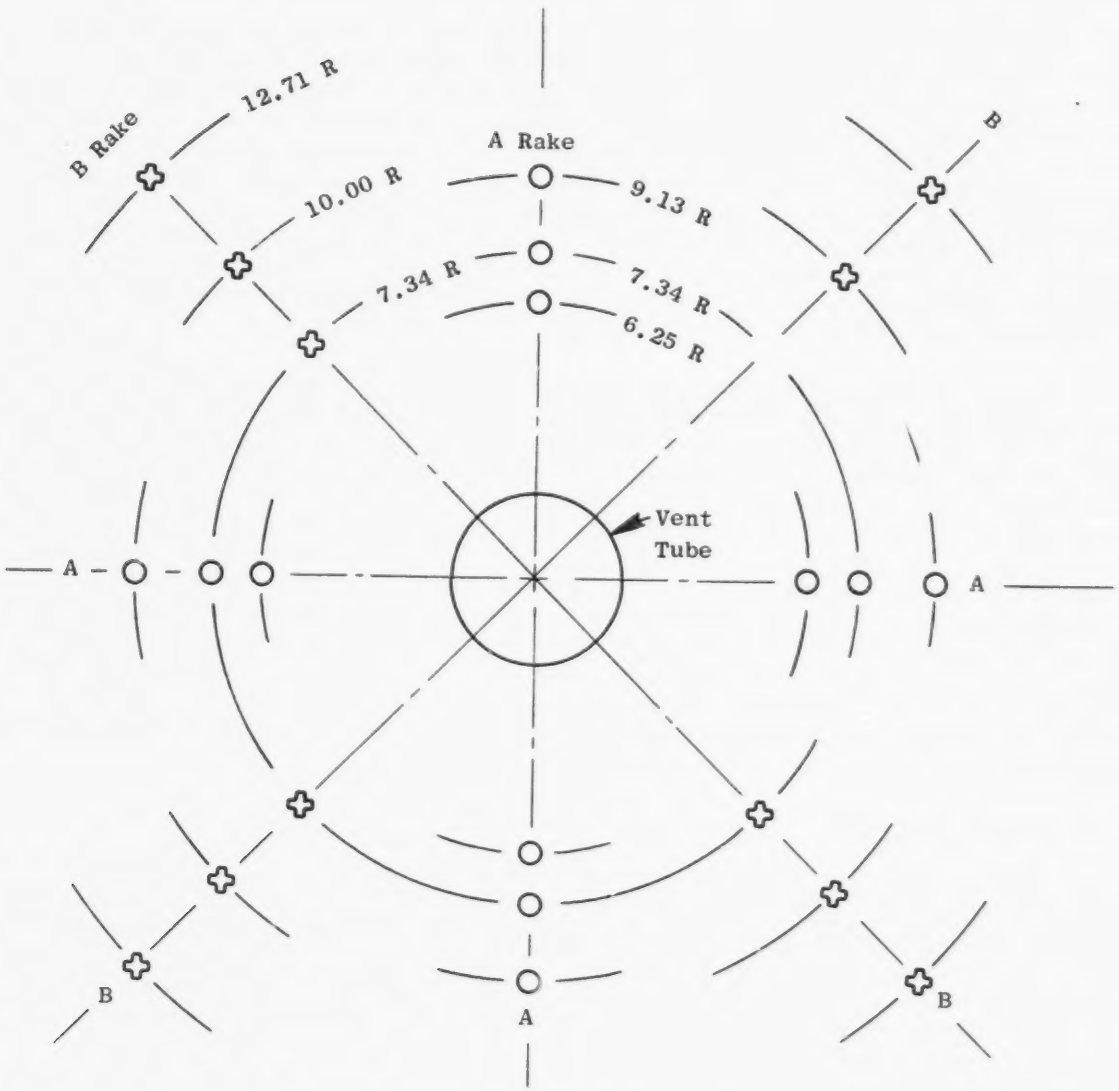


Figure 25. CFM56 Rake Sampling Pattern.

Figure 26 is a photograph of the rake system mounted behind the CFM56 engine in Cell 6. The view is aft looking forward and shows the engine exhaust nozzle, the core nozzle, and other internal components. Figure 27 (forward looking aft) shows the right side of the rake system with the drive mechanism and the engine exhaust nozzle; the Cell 6 augmentor pipe is in the background.

The sampling rake was connected to the analysis system by two 3/8-inch-O.D., steam-traced, sample lines (one each for Rakes A and B). The sample lines were about 45 feet long. The sample lines are connected to the analysis system through a valve box containing two three-way valves as shown in Figure 28. The lines are connected such that, by proper manipulation of the three-way valves, a sample from one rake is routed to the smoke console while the sample from the other rake is pumped to the gas-analysis system. The dump pump is used to maintain the required dump flow rate of 20 liters per minute. With this system, the calculated sample-line transit time is 0.96 seconds. The back-flush air supply is used during engine starting and shutdown to prevent fuel from entering the sampling system.

Figure 29 shows the emissions analysis system; the gas analyzers are in the background, and the smoke measurement console is in the foreground. On top of the smoke console is the valve box control and the control and readout for the rake system. This gas-analysis system is generally used for engine emissions tests and was specifically designed and packaged by GE for compactness and portability. The four analyzers are manufactured by Beckman Instruments, Inc. The CO (Model 865) and CO_2 (Model 864) analyzers are both nondispersive infrared instruments. The NO_x analyzer is a Model 951 heated chemiluminescence analyzer with thermal converter, and the HC analyzer is a Model 402 heated flame-ionization instrument. The sample pumps, the flexible lines (to permit rake rotation), and the valve box are electrically heated. All other portions of the sample system are steam traced. Temperatures throughout the system were monitored with fourteen chromel-alumel thermocouples.

5.3 ENGINE TEST DATA

The six separate engine tests were conducted between October 28 and November 16, 1977. The tests were scheduled to obtain as wide a range of ambient conditions as practicable. As indicated in Table 6, a fairly wide range of ambient conditions did result, including one test run with visible precipitation. The total spread was 39 to 70° F ambient temperature, 28.85 to 29.52 inches of mercury barometric pressure, and 18 to 72 gr/lb absolute humidity.

In each test, five separate engine-power conditions were run. At each power condition, emissions were measured separately on samples from Rake A and Rake B at the 0° rotation position. At the zero position, Rake A is vertical and horizontal with orifices located as shown in Figure 25.

A complete tabulation of the CFM56 engine test data is given in Appendix B. Note that "ambient" temperature and pressure are measured at the fan inlet rather than outside the test cell. The difference in pressure may be

View is Aft Looking Forward into Exhaust Nozzle

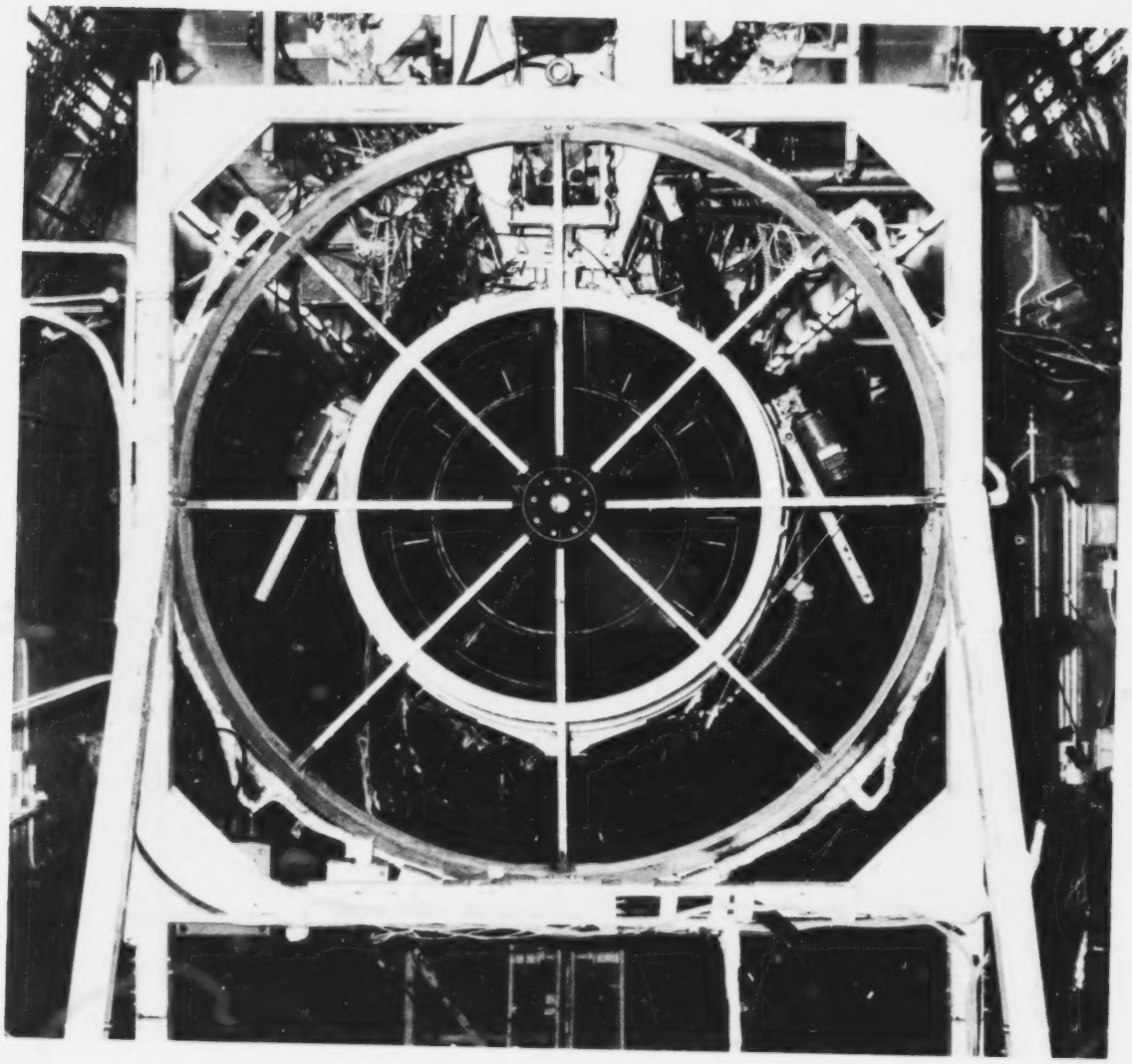


Figure 26. Rotating Rake System Mounted Behind CFM56 Engine with Confluent Exhaust Nozzle.

View is Forward Looking Aft with Cell Augmentor in Background

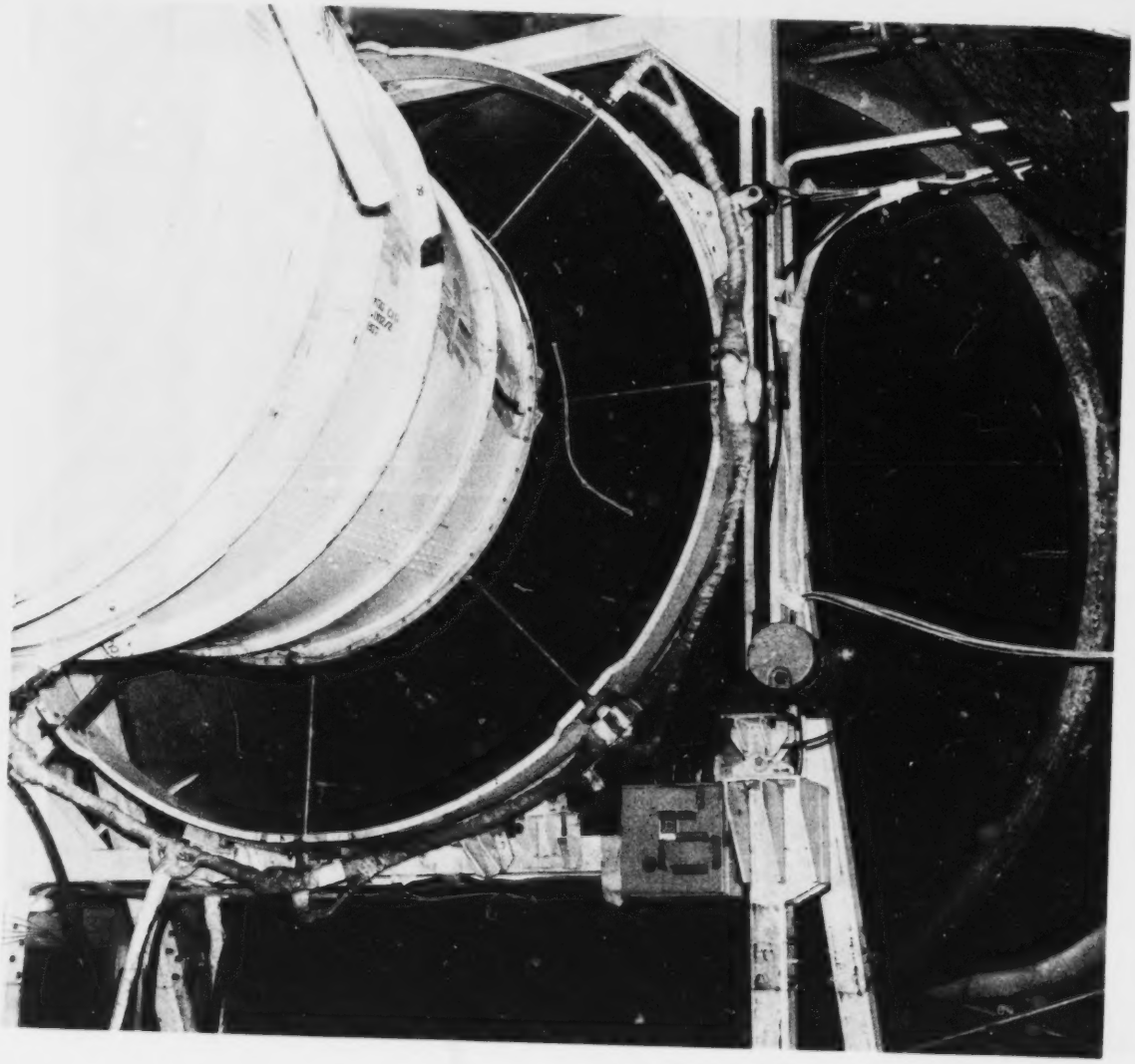


Figure 27. Rake System Mounted Behind CFM56 Engine.

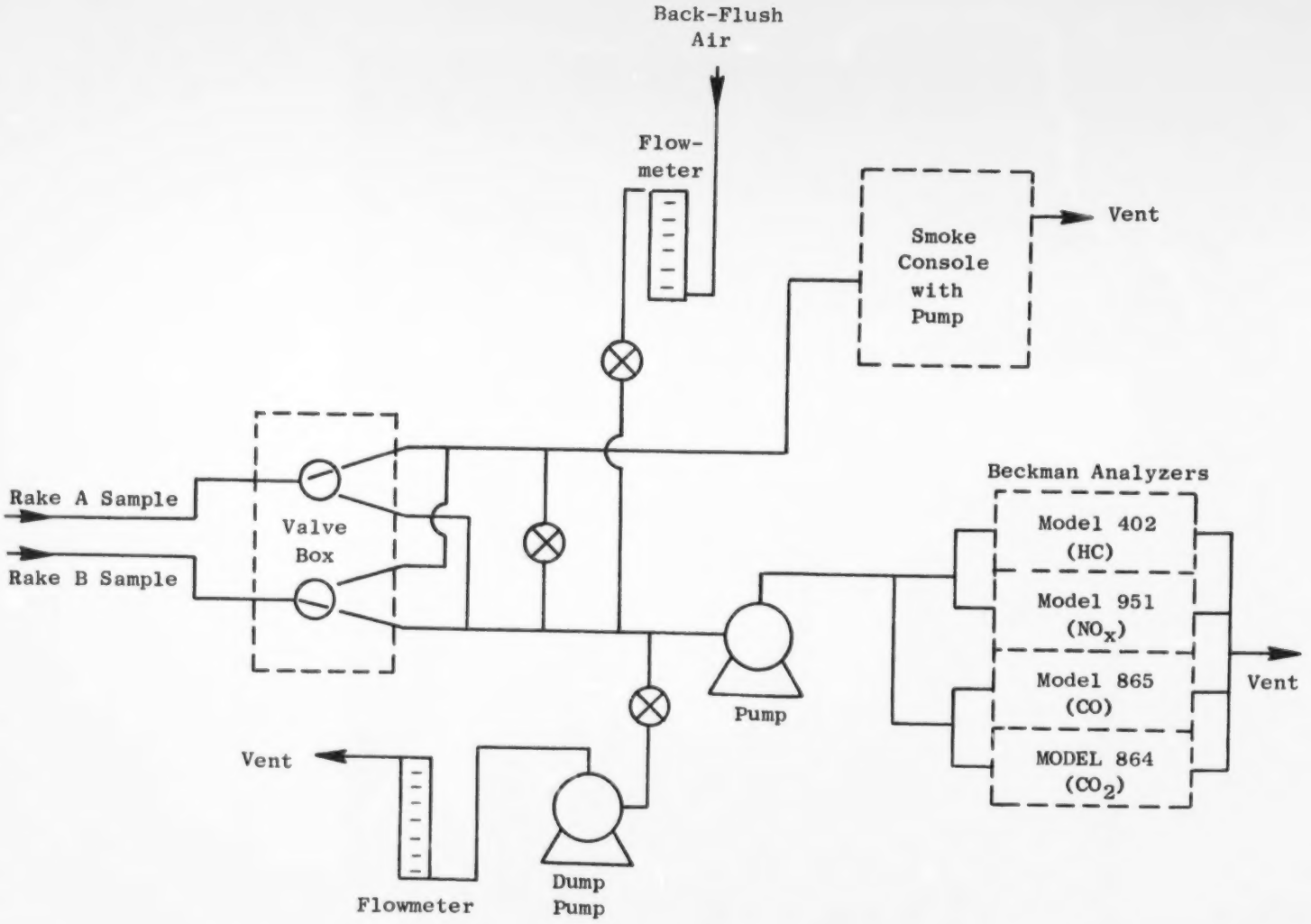


Figure 28. Emissions Sampling and Analysis System.

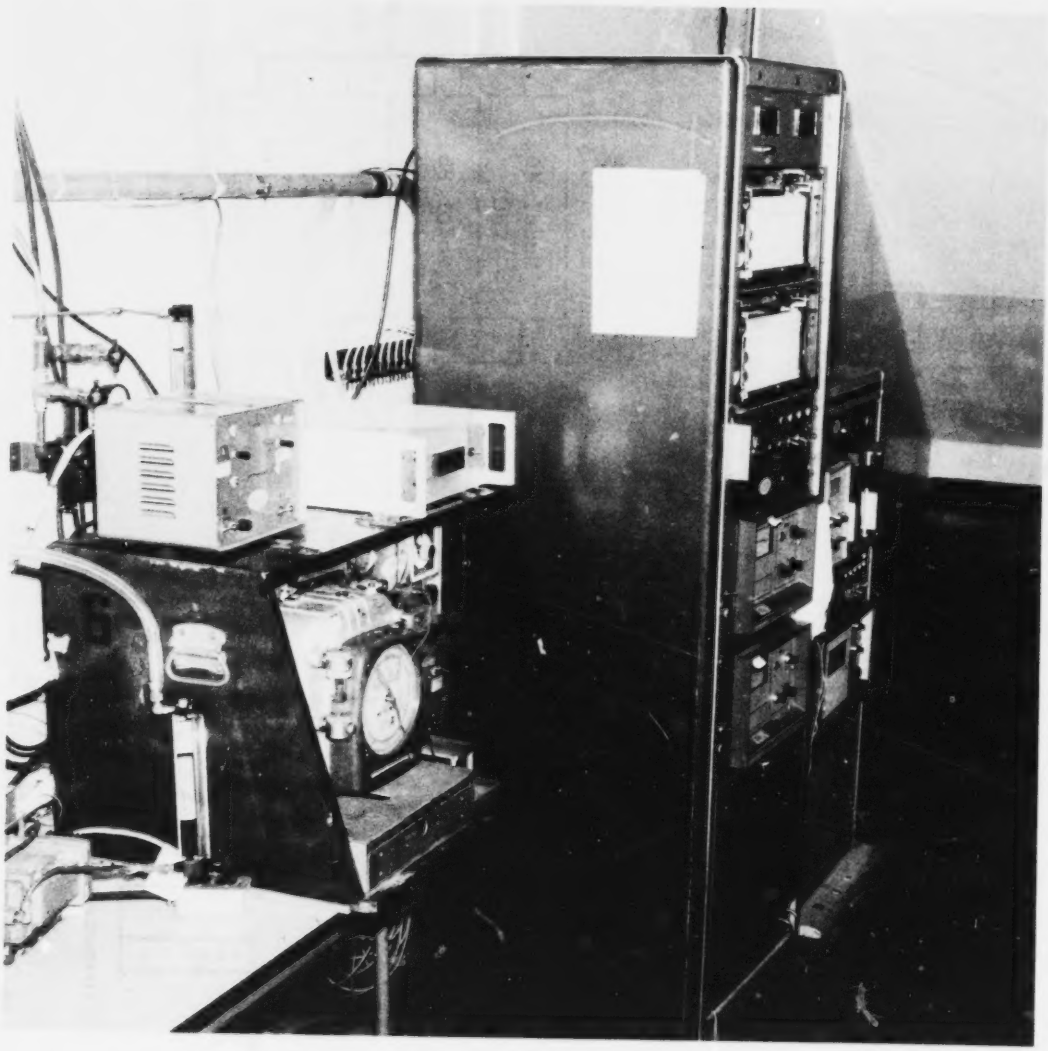


Figure 29. Smoke Measurement and Gas Analysis Systems.

Table 6. Range of Ambient Conditions During Engine Tests.

Engine Test Run	Date	Temperature, ° F	Pressure, in. of Hg	Humidity gr/lb
1	10/28/77	54.7 - 55.7	29.30 - 29.52	47 - 50
2	11/03/77	69.0 - 70.0	29.05 - 29.38	72
3	11/10/77	39.7 - 43.7	29.05 - 29.22	18 - 19
4	11/10/77	38.7 - 39.1	29.07 - 29.30	18 - 19
5	11/14/77*	49.7 - 60.0	28.97 - 29.46	22 - 39
6	11/16/77	49.0 - 49.8	28.85 - 29.11	46 - 47

*Run in two segments (11/14/77) and 11/15/77)

important at the highest power conditions where appreciable pressure drop occurs in the inlet stack.

The initial data from this test series showed that the fuel/air ratio from Rake B varied from about 79% of the calculated value (FAR57) at idle power to about 96% of FAR57 at takeoff power. This is within a reasonable range based on the sample orifice locations. The sample fuel/air ratio from Rake A, however, ranged from 56% at approach power to 81% of FAR57 at takeoff power. This is considerably lower than had been anticipated since the orifice locations were selected to obtain good agreement with the core fuel/air ratio. The cause of this discrepancy was found to be the flow disturbance in the wake of the engine support pylon which affected the top vertical portion of Rake A in the 0° position. A detailed examination of total temperature and pressure surveys at the exhaust plane revealed that the magnitude of the pressure and temperature variations over Rake A orifices were sufficient to cause the observed discrepancy in fuel/air ratio. During several of the tests, the rake was rotated to further investigate the circumferential variation in fuel/air ratio. However, since emission indices do not change with air dilution, the measured gaseous emission indices were quite independent of rake rotation. Some effect on measured smoke levels due to circumferential variation in fuel/air ratio was anticipated. However, the variation in measured smoke levels with circumferential location did not appear to be related to local fuel/air ratio variations. This is due in part to the fact that significant smoke levels (SN > 5) were measured only at the high power conditions (climb and takeoff), where the fuel/air ratio variations were relatively small. A complete discussion of the effect of the support pylon flow disturbance on measured fuel/air ratio is given in Appendix C of this report.

Table 7 shows corrected emission indices for the engine tests. EICO and EIHC are corrected for P_3, and $EINO_x$ is corrected for P_3 and humidity, as was done for the rig-test data. The measured values for emission index were the average of Rake A and B samples, each obtained in the 0° rake position.

Figure 30 shows CO emission index for the CFM56 engine tests at idle and 1.5 idle power. Both measured and corrected data (from Table 7) are shown. For comparison, a line determined by the Calspan-EPA correlation of the uncorrected data is also shown. This line is drawn through the average emission index with a curvature determined by analysis of the rig data (T_{3Coef} = 0.006443) as presented in Reference 1. Note that this is not a completely realistic comparison of the two correction methods since the relative values depend to some extent on the reference conditions chosen. For the T_3 reference conditions shown in Figure 30, the Calspan-EPA correlation gives a somewhat higher EI than does the EI corrected for P_3. This comparison manifests the obvious fact that, if test P_3 is close enough to the reference value, it makes no difference whether a P_3 correction is included in the data analysis.

It might also be pointed out that, in Figure 30, the corrected curve is continuous and defines the change in EICO along the engine operating line since P_3 Ref is defined to be at T_3. The Calspan-EPA correlation is discontinuous because it defines the change of EICO with T_3 at constant P_3 (or constant power level).

Table 7. Engine Test Emission Indices Corrected for Pressure and Humidity.

Power	T_3, ° F	P_3, psia	P_3R, psia	Corrected Emission Index		
				EICO	EIHC	$EINO_x$
Idle	368.9	51.80	55.09	24.60	1.03	3.69
	394.6	52.30	60.06	22.59	0.42	4.77
	351.7	51.80	50.48	30.30	1.01	3.70
	343.8	51.60	48.93	34.76	1.31	3.76
	363.3	51.90	52.88	28.29	1.00	3.94
	363.1	51.10	52.84	26.25	0.92	3.51
1.5 Idle	430.4	67.70	69.55	14.36	0.75	4.39
	456.8	67.90	77.41	14.34	0.25	5.66
	418.0	67.60	66.11	17.17	0.32	4.44
	421.3	70.40	67.01	17.98	0.51	5.13
	436.4	70.00	71.27	15.48	0.57	4.90
	429.5	67.20	69.29	15.81	0.32	4.69
30%	615.5	140.50	140.20	3.61	0.40	8.41
	645.1	140.20	154.85	4.44	0.12	9.51
	597.9	139.40	127.36	6.01	0.13	7.55
	592.0	142.60	129.22	5.45	0.19	8.02
	612.8	141.60	138.90	5.15	0.16	7.71
	611.5	141.30	138.29	5.11	0.16	7.65
85%	880.9	296.30	304.71	0.77	0.05	14.79
	910.0	293.90	327.28	1.40	0.04	15.99
	847.0	294.90	279.55	1.25	0.11	12.88
	848.6	296.40	280.71	1.25	0.	13.88
	892.0	292.00	313.21	1.31	0.08	15.34
	869.8	293.90	296.34	1.19	0.05	14.67
100%	933.2	336.70	345.91	0.77	0.05	17.19
	968.1	335.70	375.02	1.19	0.	18.93
	899.6	336.00	319.11	1.19	0.11	15.32
	898.9	336.10	318.56	1.14	0.11	16.50
	948.6	335.60	358.60	1.13	0.08	18.08
	920.3	333.00	335.48	0.59	0.05	17.34

Corrected EICO = EICO $(P_3/P_3 \text{ Ref})^{1.5}$

Corrected EIHC = EIHC $(P_3/P_3 \text{ Ref})^{2.5}$

Corrected $EINO_x$ = $EINO_x$ $(P_3 \text{ Ref}/P_3)^{0.37}$ exp -18.8 (44 - Humidity)/7000

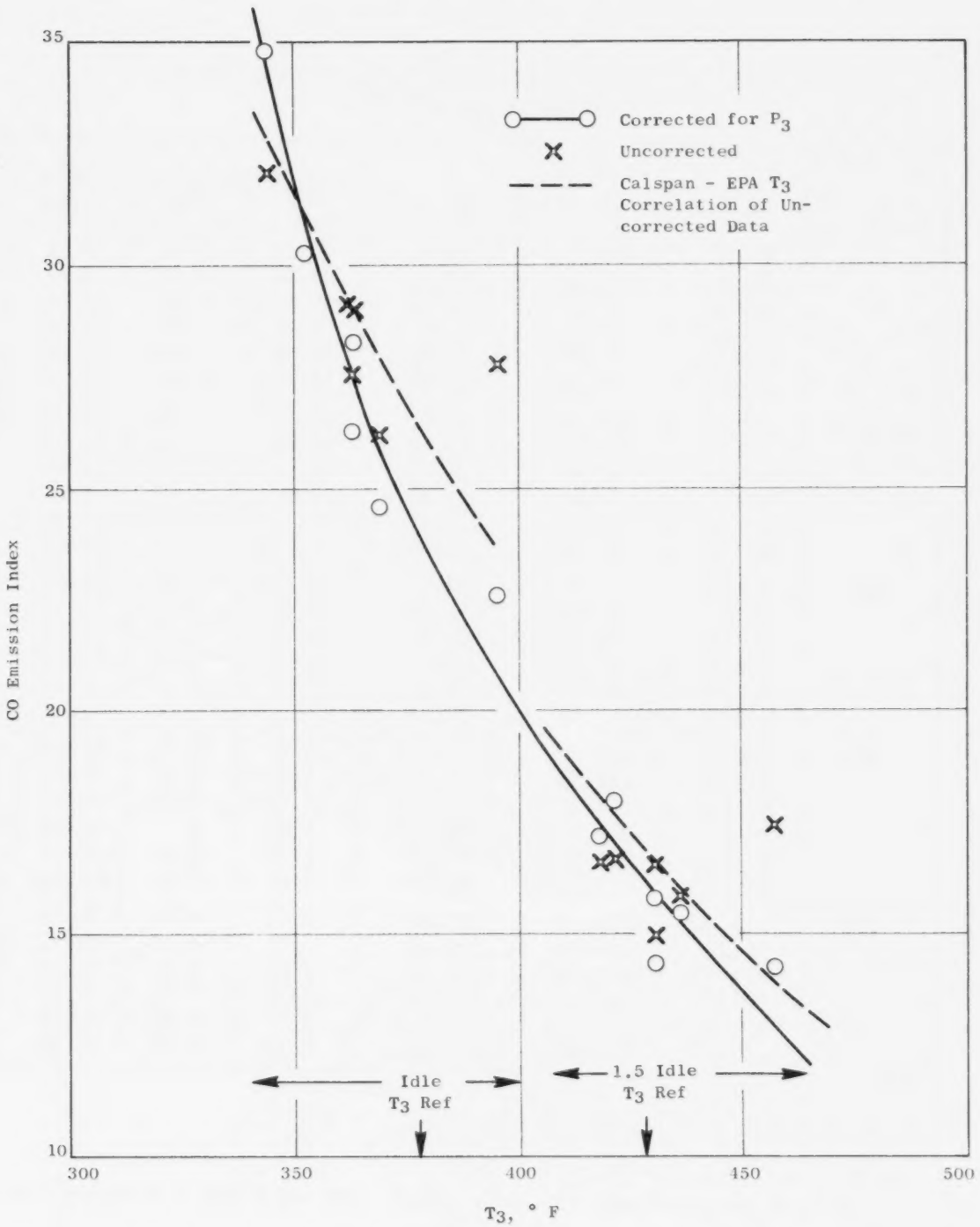


Figure 30. Comparison of Corrected and Uncorrected CO Emission Index for CFM56 Engine Tests at Idle and 1.5 Idle.

Figure 31 shows comparison of NO_x emission index corrected for humidity with $EINO_x$ corrected for humidity and P_3. In this case, the P_3 correction has very little effect on $EINO_x$, mainly because $EINO_x$ varies only as the 0.37 power of pressure. In addition, the reference value of P_3 is quite close to the pressure obtained during the engine tests.

Similar comparisons can be made for hydrocarbon emission index. However, in this case, the rather small differences considered are insignificant compared with the scatter in the data observed at the very low levels of emission index encountered.

5.4 CALCULATION OF EPA PARAMETER FOR ENGINE TESTS

The engine-test data may be used to calculate the EPA parameter. The calculation method and standard will follow the recently proposed methods (Reference 5) since it is assumed that the EPA will eventually adopt this format. To maintain consistency in this report, the SI units of the standards have been converted to the corresponding English units. The appropriate standards for comparison are for Class T2 engines, newly manufactured. The 22,000-lbf thrust version of the CFM56 engine does not exceed 25 to 1 rated pressure ratio and thus does not benefit from the increased NO_x standard allowed the higher pressure ratio engines.

Table 8 summarizes the CO EPA parameter calculation for the six engine tests. In order to demonstrate the variability of these data, the mean and standard deviation of the various values involved in the calculation are tabulated. The emission indices tabulated for idle and 30% power level have been corrected for P_3 by using the pressure-corrected data of Table 8 and for T_3 using a correction factor derived from the rig tests. The procedure involves a linear regression fit of ln EI versus T_3 to obtain the T_3 coefficient which is the slope of the regression line. This procedure is fully explained in Reference 1. Alternatively, the pressure-corrected engine test data could be plotted against T_3, as in Figure 30, and the "average" EI obtained from the curve at T_3 Ref.

For these calculations, the reference T_3 and P_3 have been obtained from the CFM56 certification cycle (1976). The reference values could have been obtained from the current CFM56 status cycle or from the operating cycle which matches the test engine. For actual engine certification to these standards, it is expected that reference conditions will be obtained from the production-engine status cycle or the best estimate of this cycle available at the time of certification.

Measured engine fuel flow is used in the present calculations to demonstrate test-to-test variability of this important variable and also because the EPA procedure requires the measured engine fuel flow to be used. Due to planned improvements in component efficiency, the certification cycle predicts considerably lower fuel flow than measured on this development engine. If the final certification test were performed on a production engine, the measured fuel flow corrected to standard-day conditions would correspond to the status cycle. It should be noted that, although the measured thrust is corrected to

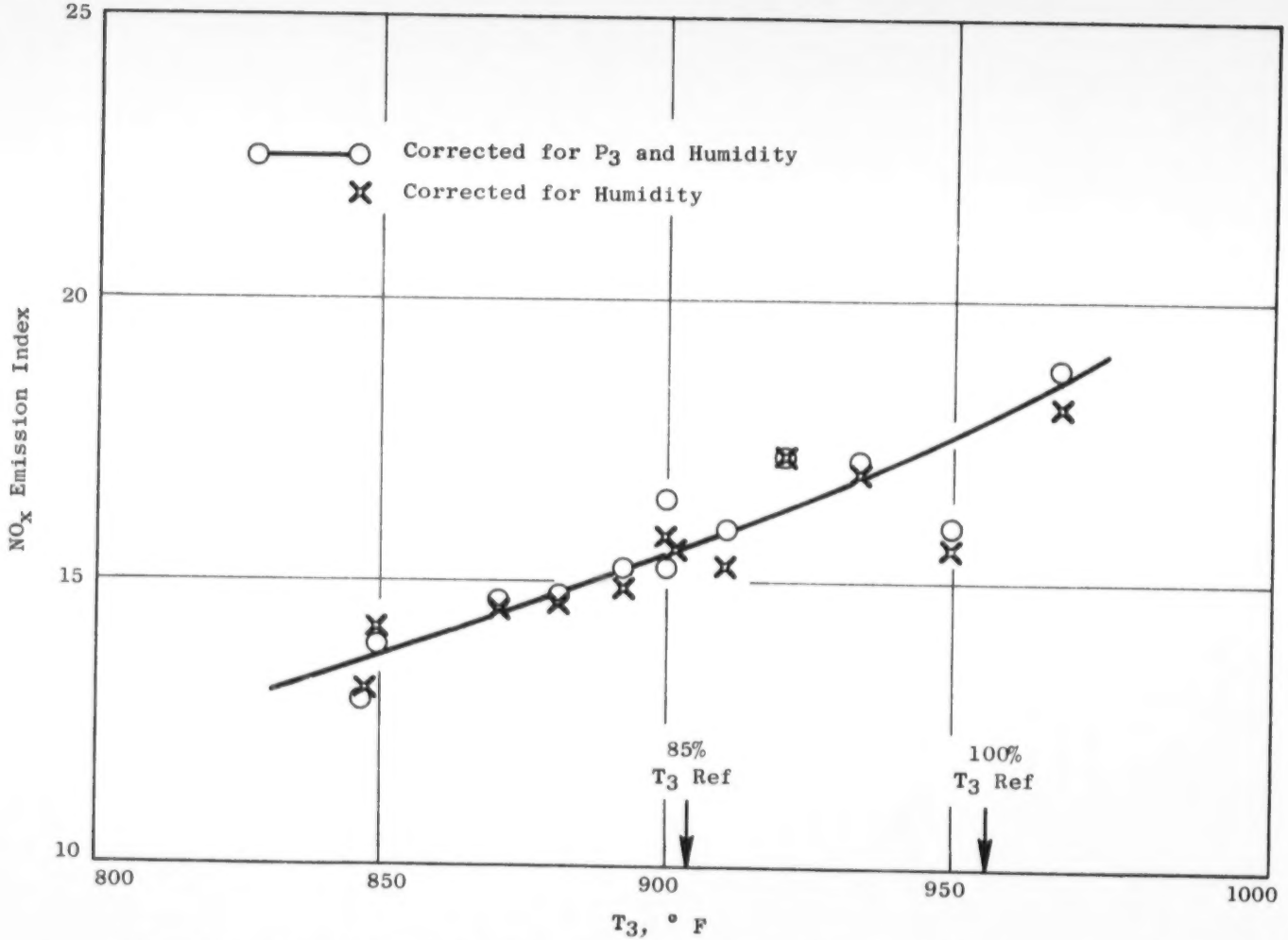


Figure 31. Comparison of Corrected and Uncorrected NO_x Emission Index for CFM56 Engine Tests at 85% and 100% of Takeoff Power.

Table 8. CO EPA Parameter for CFM56 Engine Tests.

- Emissions Data Corrected to Certification Cycle (1976)

Condition - Parameter	Test Number						Mean	SDEV	CV*
	1	2	3	4	5	6			
Idle - T_3 Ref = 378° F									
COEI (Corrected for P_3 and T_3)	22.27	27.08	22.73	23.92	24.09	22.30	23.73	1.82	0.077
Fuel Flow, pph	863	885	860	848	867	851	862.3	13.2	0.015
TIM, hr	← 0.4333 →								
Mass/Mode, lb	8.33	10.38	8.47	8.79	9.05	8.22	8.87	0.80	0.090
30% - T_3 Ref = 639° F									
COEI (Corrected for P_3 and T_3)	3.04	4.64	4.13	3.86	4.25	4.17	4.02	0.54	0.134
Fuel Flow, pph	2465	2528	2477	2509	2508	2538	2504	28.4	0.011
TIM hr	← 0.06667 →								
Mass/Mode, lb	0.50	0.78	0.68	0.65	0.71	0.71	0.67	0.095	0.141
85% - T_3 Ref = 904° F									
COEI (Corrected for P_3)	0.77	1.40	1.25	1.25	1.31	1.19	1.20	0.21	0.18
Fuel Flow, pph	6795	6875	6686	6773	6821	6806	6793	62.5	0.009
TIM, hr	← 0.03667 →								
Mass/Mode, lb	0.19	0.35	0.31	0.31	0.33	0.30	0.30	0.06	0.19
100% - T_3 Ref = 956° F									
COEI (Corrected for P_3)	0.77	1.19	1.19	1.14	1.13	0.59	1.00	0.26	0.26
Fuel Flow, pph	8092	8232	7969	8007	8249	8070	8103	115.2	0.014
TIM, hr	← 0.01167 →								
Mass/Mode, lb	0.07	0.11	0.11	0.11	0.11	0.06	0.095	0.023	0.25
Sum of Mass/Mode, lb	9.09	11.62	9.57	9.86	10.20	9.29	9.94	0.91	0.092
Rated Thrust, lbf	← 22000 →								
EPA Parameter, lbm/1000 lbf	0.413	0.528	0.435	0.448	0.464	0.422	0.452	0.042	0.092
EPA Standard, lbm/1000 lbf	← 0.354 →								

*CV = Coefficient of Variation = SDEV/Mean

standard-day conditions, the EPA procedure does not specify that such a correction be made to the fuel flow. If the final certification test were performed on a development engine, presumably with inferior performance, the question of what fuel flow to use in the EPAP calculations would need to be resolved.

In Table 8, TIM is the EPA specified time-in-mode, and mass/mode is the product of EI, TIM, and fuel flow. The total mass/mode is determined mainly by the CO at idle; this accounts for about 89% of the total. Similarly, the total variation in EPAP is determined mainly by the variation in fuel flow and EI at idle. The average value of CO EPAP is 0.452; this exceeds the proposed standard by 28%. The coefficient of variation of the average EPAP is 9.2% - due mainly to the variability of the EI at Idle (although CO variability is higher at other power levels, the high EI levels at idle most strongly affect the EPAP).

Table 9 is a summary of the HC EPA parameter calculations for the six engine tests. The fuel flow and TIM for each test are the same as on Table 8 and are not repeated. As with the CO EPAP, the major contribution to HC is at the idle operating mode. These tests show that the engine meets the EPA standard for HC by a considerable margin; the average EPAP is only 20% of the standard. The coefficient of variation in HC EPAP is 22%.

Table 10 summarizes the NO_x EPA parameter calculations. For NO_x, the major contribution to the EPAP is in the climb-out mode (85% power) where 46% of the NO_x is formed; however, the other operating modes all contribute significantly to the total. Excellent reproducibility in the NO_x EPAP is obtained; the coefficient of variation is only 2.9%. The NO_x EPAP for this engine exceeds the standard by 23%.

Figure 32 shows CFM56 engine smoke number plotted against corrected thrust as specified in the EPA procedures (Reference 5). It should be noted that samples averaged over the entire exhaust nozzle of this confluent engine would exhibit much lower smoke numbers than core engine samples, such as taken in this program, due to dilution with fan air. The core engine smoke number for the CFM56 meets the EPA standard with considerable margin as shown in Figure 32.

Table 9. HC EPA Parameter for CFM56 Engine Tests.

- Emissions Data Corrected to Certification Cycle (1976)

Condition - Parameter	Test Number						Mean	SDEV	CV*
	1	2	3	4	5	6			
Idle - T_3 Ref = 378° F									
HCEI (Corrected for P_3 and T_3)	0.79	0.68	0.47	0.48	0.65	0.60	0.61	0.12	0.20
Mass/Mode, lb	0.30	0.26	0.18	0.18	0.24	0.22	0.23	0.047	0.20
30% - T_3 Ref = 639° F									
HCEI (Corrected for P_3	0.40	0.12	0.13	0.19	0.16	0.16	0.19	0.10	0.55
Mass/Mode, lb	0.07	0.02	0.02	0.02	0.03	0.03	0.033	0.019	0.56
85% - T_3 Ref = 904° F									
HCEI (Corrected for P_3)	0.05	0.04	0.11	0	0.08	0.05	0.055	---	---
Mass/Mode, lb	0.01	0.01	0.03	0	0.02	0.01	0.013	---	---
100% - T_3 Ref = 956° F									
HCEI (Corrected for P_3)	0.05	0	0.11	0.11	0.08	0.05	0.067	---	---
Mass/Mode, lb	0.005	0	0.010	0.010	0.008	0.005	0.006	---	---
Sum of Mass/Mode, lb	0.385	0.290	0.24	0.22	0.298	0.265	0.283	0.058	0.21
Rated Thrust, lbf	◄ 22000 ►								
EPA Parameter, lbm/1000 lbf	0.018	0.013	0.011	0.010	0.014	0.012	0.013	0.0028	0.22
EPA Standard, lbm/1000 lbf	◄ 0.0657 ►								

*CV = Coefficient of Variation = SDEV/Mean

Table 10. NO_x EPA Parameter for CFM56 Engine Tests.

- Emissions Data Corrected to Certification Cycle (1976)

Condition - Parameter	Test Number						Mean	SDEV	CV*
	1	2	3	4	5	6			
Idle - T_3 Ref = 378° F									
NO_xEI (Corrected for P_3, T_3, Humidity)	3.81	4.50	4.06	4.24	4.15	3.70	4.08	0.29	0.071
Mass/Mode, lb	1.42	1.73	1.51	1.56	1.56	1.36	1.52	0.13	0.085
30% - T_3 Ref = 639° F									
NO_xEI (Corrected for P_3, T_3, Humidity)	8.98	9.35	8.70	9.14	8.29	8.26	8.78	0.45	0.051
Mass/Mode, lb	1.48	1.58	1.44	1.53	1.39	1.40	1.47	0.075	0.051
85% - T_3 Ref = 904° F									
NO_xEI (Corrected for P_3, T_3, Humidity)	15.93	15.68	15.48	16.60	15.95	16.38	16.00	0.42	0.026
Mass/Mode, lb	3.97	3.95	3.80	4.12	3.99	4.09	3.99	0.11	0.029
100% - T_3 Ref = 956° F									
NO_xEI (Corrected for P_3, T_3, Humidity)	18.55	18.18	14.48	19.95	16.48	19.53	18.53	1.21	0.065
Mass/Mode, lb	1.75	1.75	1.72	1.86	1.59	1.84	1.75	0.097	0.055
Sum of Mass/Mode, lb	8.62	9.81	8.47	9.07	8.53	8.69	8.73	0.25	0.029
Rated Thrust, lbf	← 22000 →								
EPA Parameter, lbm/1000 lbf	0.392	0.410	0.385	0.412	0.388	0.395	0.397	0.11	0.029
EPA Standard, lbm/1000 lbf	← 0.3247 →								

*CV = Coefficient of Variation = SDEV/Mean

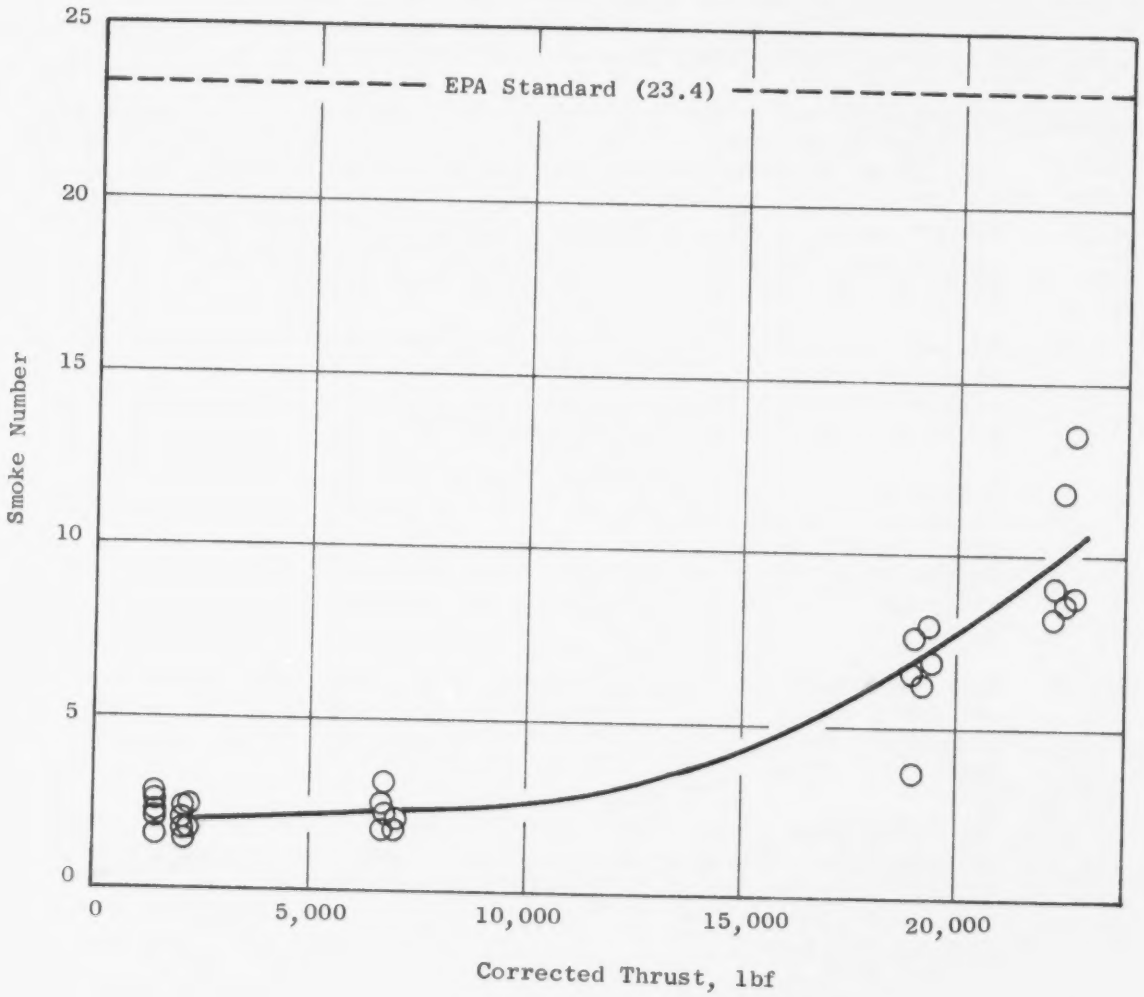


Figure 32. Core Engine Smoke Number for CFM56 Engine Tests.

6.0 CONCLUSIONS

The following are signficant conclusions resulting from work conducted on this program:

1. The effects of ambient temperature, pressure, and humidity can best be evaluated through the consequent changes in combustor inlet conditions of temperature, pressure, and humidity.

2. CO and HC emission levels generally decrease with increasing combustor inlet temperature (T_3) and pressure (P_3). For the CFM56 combustor, CO and HC emissions are very sensitive to T_3 and P_3. However, the effect of P_3 is small (<10%) over a typical range of variation in ambient pressure when tests are conducted at or near sea level. No significant change in CO and HC with humidity was noted for the CFM56 in the range of moisture levels investigated.

3. NO_x emission levels generally increase with increasing T_3 and P_3 and decrease with increasing humidity. As with most gas turbine combustion systems, the CFM56 combustor NO_x level is moderately sensitive to T_3 and humidity and slightly sensitive to P_3.

4. A data-analysis methodology was used which allows convenient presentation of data obtained over wide ranges of T_3, P_3, humidity, and power level. In this method, measured CO and HC levels are corrected to reference P_3 and correlated against T_3. The measured NO_x level is corrected to reference P_3 and humidity and correlated against T_3.

5. Corrected emission levels were used to calculate EPA parameters for the CFM56 engine tests. Coefficients of variation of the calculated parameters for the six tests were 9% for CO, 22% for HC, and 3% for NO_x.

6. The EPA procedure specified for measurement of aircraft gas turbine emissions does not adequately define the sampling pattern for high-bypass, turbofan engines with confluent core and fan exhaust. In particular, the meaning of "representative" sample should be clarified.

7. Significant circumferential variations in total temperature and total pressure can occur at the exhaust plane of engines with confluent core and fan exhaust. These variations are in addition to the normally severe radial gradients and can cause distorted sample fuel/air ratios if the sampling system is not carefully designed. Measured emission indices are not strongly influenced by this fuel/air ratio distortion, but measured smoke levels are probably affected.

8. Accurate measurement and control of inlet humidity has been demonstrated in a full-scale combustor rig-test facility.

APPENDIX A

RIG TEST DATA

This appendix presents complete tabulations of the CFM56 combustor rig-test data. Nomenclature used in the data tabulation is defined below. The tabulations are divided into four sections categories on each page.

The date tabulated under Simulated Engine Conditions includes the EPA specified engine-power level, simulated ambient conditions for the particular test point, and engine parameters calculated using the appropriate engine cycle as discussed in a previous section of this report.

The second category is actual rig conditions. These measured values were intended to be the same as the simulated conditions.

The third group of data is obtained from the measured emissions values.

The fourth group of data lists emissions values corrected to simulated engine conditions. For this correction, only a pressure effect on NO_x and smoke is considered. The NO_x emission index is taken to be proportional to the 0.37 power of the pressure, and the smoke number is taken to be proportional to the 1.5 power of pressure. These correction factors were derived from previous correlation studies on similar CFM56 combustors. The major purpose of these correction factors is to account for the fact that, at the highest power levels (85 and 100% power), the rig tests were conducted at pressures considerably lower than the true engine condition.

NOMENCLATURE FOR RIG TEST DATA

CASE - Consecutively numbered on table

RDG - Test reading number in time sequence

POINT* - Coded test point number

*POINT Code - First character, power: 1 = IDL, 2 = 1.5IDL, 3 = APP, 4 = CLI, 5 = T/O
- Second character, replication: A or B for rig test
- Third and fourth characters, test point: 0 through 22 per test point schedule.

DATE	-	Test Date
POWER	-	Nominal engine power level: IDL (Idle), 1.5IDL (1.5 Idle), APP (Approach), CLI (Climb), T/O (Takeoff)
FN, LBS	-	Net thrust
FNK, LBS	-	Corrected thrust - FN*14.696/PAMB
TAMB, F	-	Ambient temperature
PAMB, PSIA	-	Ambient pressure
HUM, GR/LB	-	Ambient humidity
P3, PSIA	-	Compressor discharge pressure
T3, F	-	Compressor discharge temperature
W36, PPS	-	Combustor airflow
WFE, PPH	-	Engine fuel flow
FAR4	-	Combustor fuel/air ratio
CO, PPM	-	CO concentration (wet)
CO2, PCT	-	CO_2 concentration (wet)
HC, PPM	-	Hydrocarbons (equivalent CH_4) concentration (wet)
NOX, PPM	-	NO_x concentration (wet)
EICO	-	CO emission index, lb of CO per 1000 lb of fuel
EIHC	-	HC emission index, lb of HC per 1000 lb of fuel
EINOX	-	NO_x emission index, lb of NO_x per 1000 lb of fuel
SMOKE	-	Smoke number
FARGAS	-	Fuel/air ratio calculated from sample composition
EFF, PCT	-	Combustion efficiency calculated from sample composition

CFM56 COMBUSTOR RIG DATA

CASE	1	2	3	4	5	6	7	8	9	10
RDG	1	23	4	26	5	9	6	52	10	51
POINT	1A 1	1B 1	1A 2	1B 2	1A 3	1B 3	1A 4	1B 4	1A 5	1B 5
DATE	11/19/76	11/22/76	11/19/76	11/22/76	11/19/76	11/22/76	11/19/76	11/23/76	11/22/76	11/23/76
SIMULATED ENGINE CONDITIONS										
POWER	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL
FN, LBS	1260.	1260.	1252.	1252.	1246.	1246.	1238.	1238.	1234.	1234.
FNK, LBS	1286.	1286.	1278.	1278.	1272.	1272.	1264.	1264.	1259.	1259.
TAMB, F	19.0	19.0	39.0	39.0	59.0	59.0	85.0	85.0	105.0	105.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
P3, PSIA	48.87	48.87	48.84	48.84	48.83	48.83	48.78	48.78	48.74	48.74
T3, F	295.2	295.2	325.2	325.2	355.1	355.1	393.7	393.7	423.2	423.2
W36, PPS	15.95	15.95	15.71	15.71	15.49	15.49	15.22	15.22	15.02	15.02
WFE, PPH	843.	843.	847.	847.	851.	851.	856.	856.	859.	859.
FAR4	0.01470	0.01470	0.01500	0.01500	0.01530	0.01530	0.01560	0.01560	0.01590	0.01590
ACTUAL RIG CONDITIONS										
P3, PSIA	48.25	48.75	48.40	48.82	48.02	48.98	48.65	48.94	48.99	48.94
T3, F	298.6	297.4	321.0	317.0	348.5	356.0	386.5	393.6	419.4	424.6
W36, PPS	15.06	16.38	15.98	15.45	15.04	14.36	15.63	14.68	14.27	14.38
WFE, PPH	844.	828.	831.	832.	838.	840.	847.	844.	848.	847.
FAR4	0.01560	0.01409	0.01445	0.01499	0.01548	0.01628	0.01507	0.01599	0.01655	0.01638
HUM, GR/LB	13.4	19.7	10.6	14.0	11.5	14.9	12.0	7.4	14.9	7.3
EMISSION DATA, MEASURED										
CO, PPM	611.2	555.1	512.7	532.5	500.2	492.6	397.7	390.0	330.1	352.6
CO2, PCT	3.323	3.135	3.121	3.339	3.329	3.388	3.336	3.447	3.487	3.520
HC, PPM	130.7	70.6	75.3	63.8	50.1	45.4	23.2	14.7	16.4	8.4
NOX, PPM	32.2	29.0	32.9	31.7	36.1	40.3	39.2	39.7	41.2	42.9
EICO	36.13	34.86	32.38	31.47	29.68	28.74	23.65	22.45	18.82	19.91
EIHC	4.42	2.54	2.72	2.16	1.70	1.52	0.79	0.49	0.53	0.27
EINOX	3.12	2.99	3.42	3.08	3.52	3.86	3.83	3.76	3.86	3.98
SMOKE	5.5	3.7	3.2	2.3	3.5	2.8	4.4	3.1	3.8	3.3
FARGAS	0.01663	0.01564	0.01555	0.01664	0.01657	0.01686	0.01654	0.01708	0.01725	0.01742
EFF, PCT	98.71	98.92	98.96	99.04	99.13	99.17	99.36	99.42	99.50	99.50
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	36.13	34.86	32.38	31.47	29.68	28.74	23.65	22.45	18.82	19.91
EIHC	4.42	2.54	2.72	2.16	1.70	1.52	0.79	0.49	0.53	0.27
EINOX	3.13	2.99	3.43	3.08	3.54	3.86	3.83	3.76	3.85	3.97
SMOKE	5.6	3.7	3.3	2.3	3.6	2.8	4.4	3.1	3.8	3.3
EFF, PCT	98.71	98.93	98.97	99.05	99.14	99.18	99.37	99.43	99.51	99.51

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CF56 COMBUSTOR RIG DATA

CASE	11	12	13	14	15	16	17	18	19	20
RDG	27	124	28	125	32	95	90	133	29	126
POINT	1A 6	1B 6	1A 7	1B 7	1A 8	1B 8	1A 9	1B 9	1A10	1B10
DATE	11/22/76	12/10/76	11/22/76	12/10/76	11/22/76	12/ 6/76	12/ 6/76	12/10/76	11/22/76	12/10/76
SIMULATED ENGINE CONDITIONS										
POWER	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL
FN, LBS	1246.	1246.	1236.	1236.	1228.	1228.	1223.	1223.	1231.	1231.
FNK, LBS	1271.	1271.	1261.	1261.	1253.	1253.	1249.	1249.	1256.	1256.
TAMB, F	39.0	39.0	59.0	59.0	85.0	85.0	105.0	105.0	59.0	59.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	35.0	35.0	52.5	52.5	52.5	52.5	52.5	52.5	70.0	70.0
P3, PSIA	48.71	48.71	48.58	48.58	48.54	48.54	48.50	48.50	48.48	48.48
T3, F	324.3	324.3	353.3	353.3	391.9	391.9	421.3	421.3	352.6	352.6
W36, PPS	15.66	15.66	15.40	15.40	15.13	15.13	14.93	14.93	15.36	15.36
WFE, PPH	846.	846.	849.	849.	854.	854.	857.	857.	848.	848.
FARA	0.01510	0.01510	0.01540	0.01540	0.01580	0.01580	0.01610	0.01610	0.01550	0.01550
ACTUAL RIG CONDITIONS										
P3, PSIA	48.65	48.60	48.34	48.74	48.76	48.65	48.12	48.43	48.44	48.67
T3, F	317.9	318.7	352.2	342.1	386.5	390.2	418.8	412.1	351.9	345.9
W36, PPS	15.85	15.44	15.00	15.11	15.16	15.22	13.81	14.64	15.03	15.16
WFE, PPH	833.	838.	836.	841.	840.	869.	866.	846.	835.	842.
FARA	0.01467	0.01514	0.01564	0.01557	0.01552	0.01598	0.01758	0.01616	0.01559	0.01557
HUM, GR/LB	35.3	32.3	72.0	50.3	52.8	51.9	60.0	51.9	71.8	67.6
EMISSION DATA, MEASURED										
CO, PPM	532.8	545.8	461.8	490.4	380.7	388.2	380.8	342.5	458.6	474.5
CO2, PCT	3.256	3.261	3.409	3.254	3.456	3.617	3.885	3.402	3.376	3.345
HC, PPM	58.0	63.1	36.7	43.3	17.4	11.1	9.9	10.1	35.5	42.8
NOX, PPM	28.2	31.6	31.5	31.5	35.7	35.2	39.7	37.0	31.6	30.5
EICO	32.27	32.99	26.81	29.78	21.87	21.32	19.49	20.01	26.88	28.05
EIHC	2.01	2.18	1.22	1.51	0.57	0.35	0.29	0.34	1.19	1.45
EINOX	2.81	3.14	3.00	3.14	3.37	3.18	3.33	3.55	3.04	2.96
SMOKE	3.1	1.6	3.1	0.2	3.3	4.3	2.8	0.3	3.0	0.5
FARGAS	0.01623	0.01626	0.01694	0.01618	0.01713	0.01793	0.01926	0.01683	0.01678	0.01663
EFF, PCT	99.04	99.00	99.24	99.15	99.42	99.46	99.51	99.49	99.24	99.19
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	32.27	32.99	26.81	29.78	21.87	21.32	19.49	20.01	26.88	28.05
EIHC	2.01	2.18	1.22	1.51	0.57	0.35	0.29	0.34	1.19	1.45
EINOX	2.81	3.14	3.01	3.14	3.36	3.18	3.34	3.55	3.04	2.96
SMOKE	3.1	1.6	3.1	0.2	3.3	4.3	2.9	0.3	3.0	0.5
EFF, PCT	99.05	99.01	99.25	99.15	99.43	99.47	99.52	99.50	99.25	99.20

CFM56 COMBUSTOR RIG DATA

CASE	21	22	23	24	25	26	27	28	29	30
RDG	96	129	91	134	130	215	94	131	2	24
POINT	1A11	1B11	1A12	1B12	1B13	1D13	1A14	1B14	1A15	1B15
DATE	12/ 6/76	12/10/76	12/ 6/76	12/10/76	12/10/76	12/14/76	12/ 6/76	12/10/76	11/19/76	11/22/76
SIMULATED ENGINE CONDITIONS										
POWER	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL
FN, LBS	1214.	1214.	1209.	1209.	1196.	1196.	1192.	1192.	1382.	1382.
FNK, LBS	1239.	1239.	1234.	1234.	1220.	1220.	1216.	1216.	1281.	1281.
TAMB, F	85.0	85.0	105.0	105.0	85.0	85.0	105.0	105.0	19.0	19.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	15.856	15.856
HUM, GR/LB	105.0	105.0	105.0	105.0	175.0	175.0	175.0	175.0	14.0	14.0
P3, PSIA	48.22	48.22	48.18	48.18	47.80	47.80	47.76	47.76	53.70	53.70
T3, F	389.4	389.4	418.8	418.8	386.3	386.3	415.6	415.6	294.7	294.7
W36, PPS	15.00	15.00	14.80	14.80	14.84	14.84	14.64	14.64	17.56	17.56
WFE, PPH	851.	851.	855.	855.	848.	848.	851.	851.	918.	918.
FAR4	0.01600	0.01600	0.01630	0.01630	0.01630	0.01630	0.01660	0.01660	0.01450	0.01450
ACTUAL RIG CONDITIONS										
P3, PSIA	48.23	48.40	48.17	48.39	48.86	47.85	47.71	47.77	53.52	53.70
T3, F	389.8	379.9	404.3	414.9	375.2	382.6	411.7	405.3	292.4	298.0
W36, PPS	15.27	15.05	14.52	14.54	15.51	15.12	14.53	14.36	16.87	17.23
WFE, PPH	807.	842.	851.	845.	837.	888.	848.	841.	900.	901.
FAR4	0.01491	0.01576	0.01652	0.01640	0.01534	0.01671	0.01660	0.01669	0.01486	0.01456
HUM, GR/LB	102.7	103.4	107.1	110.2	160.5	173.0	174.3	176.8	12.9	18.9
EMISSION DATA, MEASURED										
CO, PPM	360.0	412.6	384.5	334.4	390.8	411.6	358.5	366.9	489.1	478.5
CO2, PCT	3.382	3.394	3.695	3.416	3.379	3.606	3.701	3.566	3.235	3.172
HC, PPM	14.8	23.7	13.3	10.0	25.9	22.1	10.7	17.2	101.5	56.6
NOX, PPM	29.8	30.1	32.2	33.0	25.6	29.8	27.9	27.9	32.4	29.0
EICO	21.15	24.11	20.67	19.46	22.94	22.65	19.26	20.44	29.82	29.79
EIHC	0.50	0.79	0.41	0.33	0.87	0.70	0.33	0.55	3.54	2.02
EINOX	2.87	2.89	2.84	3.16	2.47	2.70	2.47	2.55	3.25	2.97
SMOKE	3.3	1.0	3.9	1.4	1.6	1.2	3.0	1.5	3.6	4.1
FARGAS	0.01674	0.01683	0.01832	0.01690	0.01675	0.01789	0.01833	0.01767	0.01612	0.01578
EFF, PCT	99.45	99.35	99.47	99.50	99.37	99.39	99.51	99.46	98.94	99.09
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	21.15	24.11	20.67	19.46	22.94	22.65	19.26	20.44	29.82	29.79
EIHC	0.50	0.79	0.41	0.33	0.87	0.70	0.33	0.55	3.54	2.02
EINOX	2.87	2.89	2.84	3.15	2.45	2.70	2.47	2.55	3.25	2.97
SMOKE	3.3	1.0	3.9	1.4	1.5	1.2	3.0	1.5	3.6	4.1
EFF, PCT	99.46	99.36	99.48	99.51	99.38	99.40	99.52	99.47	98.95	99.10

CFM56 COMBUSTOR RIG DATA

CASE	31	32	33	34	35	36	37	38	39	40
RDG	30	127	11	50	93	132	3	25	31	128
POINT	1A16	1B16	1A17	1B17	1A18	1B18	1A19	1B19	1A20	1B20
DATE	11/22/76	12/10/76	11/22/76	11/23/76	12/ 6/76	12/10/76	11/19/76	11/22/76	11/22/76	12/10/76
SIMULATED ENGINE CONDITIONS										
POWER	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL	IDL
FN, LBS	1356.	1356.	1356.	1356.	1309.	1309.	1121.	1121.	1099.	1099.
FNK, LBS	1257.	1257.	1257.	1257.	1214.	1214.	1291.	1291.	1265.	1265.
TAMB, F	59.0	59.0	105.0	105.0	105.0	105.0	19.0	19.0	59.0	59.0
PAMB, PSIA	15.856	15.856	15.856	15.856	15.856	15.856	12.763	12.763	12.763	12.763
HUM, GR/LB	52.5	52.5	14.0	14.0	175.0	175.0	14.0	14.0	52.5	52.5
P3, PSIA	53.40	53.40	53.61	53.61	52.53	52.53	43.43	43.43	43.14	43.14
T3, F	352.8	352.8	422.7	422.7	415.1	415.1	295.8	295.8	354.0	354.0
W36, PPS	16.96	16.96	16.55	16.55	16.14	16.14	14.13	14.13	13.63	13.63
WFE, PPH	924.	924.	936.	936.	928.	928.	758.	758.	763.	763.
FAR4	0.01530	0.01530	0.01570	0.01570	0.01640	0.01640	0.01490	0.01490	0.01570	0.01570
ACTUAL RIG CONDITIONS										
P3, PSIA	53.36	53.29	53.70	53.85	52.11	52.75	43.06	43.45	43.15	42.90
T3, F	351.6	347.2	421.4	427.7	410.3	403.4	292.0	300.3	352.5	346.9
W36, PPS	16.42	17.04	17.24	16.08	15.69	16.08	13.26	13.85	13.98	13.53
WFE, PPH	912.	916.	923.	923.	942.	920.	742.	745.	758.	758.
FAR4	0.01550	0.01504	0.01492	0.01596	0.01710	0.01629	0.01557	0.01497	0.01516	0.01567
HUM, GR/LB	54.8	47.7	15.7	8.1	180.6	173.3	11.8	15.2	52.1	51.2
EMISSION DATA, MEASURED										
CO, PPM	394.7	411.2	322.0	296.9	342.1	312.7	725.8	664.0	545.1	582.6
CO2, PCT	3.418	3.290	3.482	3.463	4.050	3.496	3.180	3.211	3.424	3.338
HC, PPM	26.0	27.1	11.0	5.3	10.4	10.6	176.7	111.9	49.4	65.9
NOX, PPM	33.4	32.3	44.4	43.9	29.2	28.7	29.2	27.4	31.1	29.9
EICO	22.91	24.77	18.40	17.07	16.82	17.79	44.58	40.55	31.43	34.38
EIHC	0.86	0.93	0.36	0.17	0.29	0.35	6.22	3.91	1.63	2.23
EINOX	3.19	3.20	4.17	4.15	2.36	2.68	2.95	2.74	2.94	2.90
SMOKE	3.0	0.8	4.0	2.2	3.1	3.0	3.9	2.8	2.6	2.0
FARGAS	0.01695	0.01632	0.01722	0.01711	0.02007	0.01729	0.01600	0.01610	0.01706	0.01666
FFF, PCT	99.37	99.32	99.53	99.58	99.57	99.54	98.33	98.65	99.09	98.97
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	22.91	24.77	18.40	17.07	16.82	17.79	44.58	40.55	31.43	34.38
EIHC	0.86	0.93	0.36	0.17	0.29	0.35	6.22	3.91	1.63	2.23
EINOX	3.19	3.20	4.17	4.14	2.37	2.68	2.96	2.74	2.94	2.91
SMOKE	3.0	0.8	4.0	2.1	3.1	3.0	3.9	2.8	2.6	2.0
FFF, PCT	99.38	99.33	99.53	99.58	99.58	99.55	98.34	98.66	99.10	98.97

CFM56 COMBUSTOR RIG DATA

CASE	41	42	43	44	45	46	47	48	49	50
RDG	49	216	92	135	14	47	17	33	18	45
POINT	1B21	1C21	1A22	1B22	2A 1	2B 1	2B 2	2C 2	2A 3	2B 3
DATE	11/23/76	12/14/76	12/ 6/76	12/10/76	11/22/76	11/23/76	11/22/76	11/23/76	11/22/76	11/23/76
SIMULATED ENGINE CONDITIONS										
POWER	IDL	IDL	IDL	IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL
FN, LBS	1098.	1098.	1060.	1060.	2006.	2006.	1986.	1986.	1969.	1969.
FNK, LBS	1264.	1264.	1221.	1221.	2047.	2047.	2027.	2027.	2010.	2010.
TAMB, F	105.0	105.0	105.0	105.0	19.0	19.0	39.0	39.0	59.0	59.0
PAMB, PSIA	12.763	12.763	12.763	12.763	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	14.0	14.0	175.0	175.0	14.0	14.0	14.0	14.0	14.0	14.0
P3, PSIA	43.29	43.29	42.44	42.44	64.33	64.33	64.18	64.18	64.05	64.05
T3, F	420.0	420.0	416.4	416.4	356.7	356.7	388.0	388.0	419.3	419.3
W36, PPS	13.30	13.30	12.96	12.96	20.72	20.72	20.41	20.41	20.12	20.12
WFE, PPH	773.	773.	766.	766.	1051.	1051.	1051.	1051.	1050.	1050.
FAR4	0.01620	0.01620	0.01680	0.01680	0.01410	0.01410	0.01430	0.01430	0.01450	0.01450
ACTUAL RIG CONDITIONS										
P3, PSIA	43.60	43.04	42.45	42.36	64.28	64.58	64.15	64.34	64.30	64.12
T3, F	423.3	416.0	412.7	411.4	352.9	359.1	392.5	379.2	422.6	425.8
W36, PPS	13.05	13.74	12.73	12.90	20.50	21.24	20.33	20.37	19.84	19.37
WFE, PPH	762.	780.	769.	760.	1032.	1037.	1036.	1041.	1035.	1036.
FAR4	0.01623	0.01582	0.01721	0.01677	0.01404	0.01358	0.01420	0.01421	0.01451	0.01488
HUM, GR/LB	7.7	18.1	174.9	174.6	9.4	11.2	11.8	9.3	11.8	9.7
EMISSION DATA, MEASURED										
CO, PPM	426.6	442.7	440.6	414.0	302.2	256.0	249.8	245.3	204.5	221.4
CO2, PCT	3.524	3.735	3.838	3.508	3.062	2.954	3.124	3.147	3.141	3.257
HC, PPM	13.5	14.9	19.4	19.9	12.4	11.1	8.8	7.6	5.5	4.0
NOX, PPM	41.2	42.5	27.9	27.7	38.7	34.1	40.2	41.4	44.0	44.8
EICO	24.01	23.51	22.78	23.41	19.61	17.25	15.93	15.53	12.98	13.56
EIHC	0.44	0.45	0.58	0.65	0.46	0.43	0.32	0.28	0.20	0.14
EINOX	3.81	3.71	2.37	2.57	4.13	3.78	4.21	4.31	4.59	4.50
SMOKE	2.7	1.7	4.0	1.6	2.6	3.0	3.3	2.4	2.2	3.1
FARGAS	0.01748	0.01855	0.01907	0.01740	0.01512	0.01456	0.01540	0.01551	0.01546	0.01605
EFF, PCT	99.39	99.40	99.40	99.38	99.49	99.55	99.59	99.60	99.67	99.66
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	24.01	23.51	22.78	23.41	19.61	17.25	15.93	15.53	12.98	13.56
EIHC	0.44	0.45	0.58	0.65	0.46	0.43	0.32	0.28	0.20	0.14
EINOX	3.80	3.72	2.37	2.57	4.13	3.77	4.21	4.31	4.58	4.50
SMOKE	2.7	1.7	4.0	1.6	2.6	3.0	3.3	2.4	2.2	3.1
EFF, PCT	99.40	99.41	99.41	99.39	99.50	99.55	99.60	99.61	99.68	99.67

CFM56 COMBUSTOR RIG DATA

CASE	51	52	53	54	55	56	57	58	59	60
RDG	19	40	20	44	34	117	35	119	38	141
POINT	2A 4	2B 4	2A 5	2B 5	2A 6	2B 6	2A 7	2B 7	2A 8	2B 8
DATE	11/22/76	11/23/76	11/22/76	11/23/76	11/23/76	12/ 7/76	11/23/76	12/ 7/76	11/23/76	12/10/76
SIMULATED ENGINE CONDITIONS										
POWER	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL
FN, LBS	1949.	1949.	1932.	1932.	1975.	1975.	1949.	1949.	1929.	1929.
FNK, LBS	1980.	1989.	1972.	1972.	2016.	2016.	1989.	1989.	1969.	1969.
TAMB, F	85.0	85.0	105.0	105.0	39.0	39.0	59.0	59.0	85.0	85.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	14.0	14.0	14.0	14.0	35.0	35.0	52.5	52.5	52.5	52.5
P3, PSIA	63.88	63.88	63.74	63.74	63.96	63.96	63.66	63.66	63.50	63.50
T3, F	459.9	459.9	490.8	490.8	386.9	386.9	417.2	417.2	457.7	457.7
W36, PPS	19.75	19.75	119.47	119.47	20.33	20.33	19.97	19.97	19.61	19.61
WFF, PPH	1050.	1050.	1050.	1050.	1049.	1049.	1046.	1046.	1047.	1047.
FARB	0.01480	0.01480	0.01500	0.01500	0.01440	0.01440	0.01470	0.01470	0.01490	0.01490
ACTUAL RIG CONDITIONS										
P3, PSIA	64.09	63.86	63.92	63.77	64.03	64.84	63.58	64.08	63.37	63.12
T3, F	860.9	860.3	896.4	890.0	380.3	388.2	410.4	410.9	447.6	452.0
W36, PPS	19.84	20.16	19.23	19.13	20.37	20.50	20.02	19.86	19.57	18.90
WFF, PPH	1033.	1035.	1036.	1038.	1036.	1037.	1034.	1037.	1032.	1036.
FARB	0.01480	0.01428	0.01499	0.01509	0.01420	0.01411	0.01446	0.01461	0.01476	0.01534
HUM, GR/LB	11.7	9.9	11.9	9.3	35.9	27.7	51.9	52.7	53.0	53.5
EMISSION DATA, MEASURED										
CO, PPM	188.9	179.8	168.7	170.8	258.2	243.4	199.9	231.2	185.7	209.1
CO2, PCT	3.248	3.229	3.275	3.296	3.106	3.243	3.229	3.326	3.284	3.205
HC, PPM	2.6	2.5	2.1	1.3	6.6	4.8	6.0	2.8	2.5	1.3
NOX, PPM	49.8	49.0	54.1	53.9	38.1	39.3	39.6	39.4	42.0	45.9
EICO	11.37	11.12	10.29	10.35	16.55	14.96	12.36	13.86	11.29	13.02
EIHC	0.09	0.09	0.07	0.05	0.24	0.17	0.21	0.10	0.09	0.05
EINOX	5.03	5.02	5.42	5.36	4.01	3.97	4.02	3.88	4.19	4.70
SMOKE	4.7	1.8	3.9	2.0	1.8	3.2	2.8	2.6	2.2	1.4
FARGAS	0.01598	0.01589	0.01611	0.01621	0.01532	0.01599	0.01590	0.01640	0.01616	0.01578
EFF, PCT	99.72	99.72	99.74	99.75	99.58	99.62	99.68	99.66	99.72	99.68
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	11.37	11.12	10.29	10.35	16.55	14.96	12.36	13.86	11.29	13.02
EIHC	0.09	0.09	0.07	0.05	0.24	0.17	0.21	0.10	0.09	0.05
EINOX	5.02	5.02	5.41	5.36	4.01	3.95	4.02	3.87	4.19	4.71
SMOKE	4.6	1.8	3.9	2.0	1.8	3.1	2.8	2.6	2.2	1.4
EFF, PCT	99.73	99.73	99.75	99.75	99.59	99.63	99.69	99.67	99.73	99.69

CFM56 COMBUSTOR RIG DATA

CASE	61	62	63	64	65	66	67	68	69	70
RDG	83	139	89	118	39	41	84	123	88	122
POINT	2A 9	2B 9	2A10	2B10	2A11	2B11	2A12	2B12	2A13	2B13
DATE	12/ 6/76	12/10/76	12/ 6/76	12/ 7/76	11/23/76	11/23/76	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76
SIMULATED ENGINE CONDITIONS										
POWER	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL
FN, LBS	1913.	1913.	1939.	1939.	1903.	1903.	1886.	1886.	1871.	1871.
FNK, LBS	1953.	1953.	1980.	1980.	1943.	1943.	1925.	1925.	1909.	1909.
TAMB, F	105.0	105.0	59.0	59.0	85.0	85.0	105.0	105.0	85.0	85.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	52.5	52.5	70.0	70.0	105.0	105.0	105.0	105.0	175.0	175.0
P3, PSIA	63.35	63.35	63.48	63.48	62.98	62.98	62.84	62.84	62.33	62.33
T3, F	488.6	488.6	416.2	416.2	454.7	454.7	485.5	485.5	450.9	450.9
W36, PPS	19.34	19.34	19.91	19.91	19.42	19.42	19.15	19.15	19.18	19.18
WFE, PPH	1046.	1046.	1045.	1045.	1041.	1041.	1041.	1041.	1035.	1035.
FAR4	0.01510	0.01510	0.01470	0.01470	0.01510	0.01510	0.01530	0.01530	0.01540	0.01540
ACTUAL RIG CONDITIONS										
P3, PSIA	62.94	63.36	63.41	63.66	63.13	63.24	62.63	63.02	62.16	62.94
T3, F	484.5	481.5	428.1	411.1	449.2	456.9	486.9	483.6	448.0	446.9
W36, PPS	18.88	19.39	19.53	20.17	19.95	19.24	19.27	18.56	19.64	19.31
WFE, PPH	1045.	1034.	1026.	1040.	1029.	1029.	1043.	1034.	1033.	1027.
FAR4	0.01548	0.01492	0.01472	0.01446	0.01455	0.01507	0.01526	0.01571	0.01496	0.01513
HUM, GR/LB	52.0	51.8	64.2	66.1	104.5	103.6	102.5	106.0	166.8	166.4
EMISSION DATA, MEASURED										
CO, PPM	183.7	180.2	216.8	230.2	182.3	179.5	170.4	180.9	205.5	206.6
CO2, PCT	3.415	3.233	3.478	3.365	3.260	3.382	3.477	3.447	3.500	3.471
HC, PPM	0.8	1.0	2.5	3.4	2.7	2.8	0.7	0.7	1.8	1.9
NOX, PPM	47.0	47.5	39.5	37.5	39.2	39.3	41.0	40.6	29.3	31.1
EICO	10.75	11.13	12.44	13.64	11.17	10.60	9.79	10.48	11.72	11.88
EIHC	0.03	0.03	0.08	0.12	0.10	0.10	0.02	0.02	0.06	0.06
EINOX	4.51	4.82	3.72	3.65	3.94	3.82	3.87	3.87	2.74	2.93
SMOKE	3.5	0.7	3.4	4.1	2.5	3.0	3.1	1.8	2.4	1.9
FARGAS	0.01681	0.01590	0.01714	0.01659	0.01604	0.01665	0.01711	0.01697	0.01725	0.01711
EFF, PCT	99.74	99.73	99.69	99.66	99.72	99.73	99.76	99.74	99.71	99.70
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	10.75	11.13	12.44	13.64	11.17	10.60	9.79	10.48	11.72	11.88
EIHC	0.03	0.03	0.08	0.12	0.10	0.10	0.02	0.02	0.06	0.06
EINOX	4.52	4.82	3.72	3.65	3.94	3.81	3.87	3.87	2.74	2.92
SMOKE	3.5	0.7	3.5	4.1	2.5	3.0	3.1	1.8	2.4	1.9
EFF, PCT	99.75	99.74	99.70	99.67	99.73	99.74	99.77	99.75	99.72	99.72

CFM56 COMBUSTOR RIG DATA

CASE	71	72	73	74	75	76	77	78	79	80
RDG	85	138	13	48	36	120	21	42	86	140
POINT	2A14	2B14	2A15	2B15	2A16	2B16	2A17	2B17	2A18	2B18
DATE	12/ 6/76	12/10/76	11/22/76	11/23/76	11/23/76	12/ 7/76	11/22/76	11/23/76	12/ 6/76	12/10/76
SIMULATED ENGINE CONDITIONS										
POWER	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL
FN, LBS	1854.	1854.	2202.	2202.	2141.	2141.	2123.	2123.	2036.	2036.
FNK, LBS	1892.	1892.	2041.	2041.	1985.	1985.	1967.	1967.	1887.	1887.
TAMB, F	105.0	105.0	19.0	19.0	59.0	59.0	105.0	105.0	105.0	105.0
PAMB, PSIA	14.398	14.398	15.856	15.856	15.856	15.856	15.856	15.856	15.856	15.856
HUM, GR/LB	175.0	175.0	14.0	14.0	52.5	52.5	14.0	14.0	175.0	175.0
P3, PSIA	62.19	62.19	70.74	70.74	70.01	70.01	70.12	70.12	68.40	68.40
T3, F	481.6	481.6	356.3	356.3	416.8	416.8	490.4	490.4	481.1	481.1
W36, PPS	18.92	18.92	22.82	22.82	21.99	21.99	21.46	21.46	20.85	20.85
WFE, PPH	1034.	1034.	1150.	1150.	1145.	1145.	1148.	1148.	1131.	1131.
FAR4	0.01560	0.01560	0.01400	0.01400	0.01460	0.01460	0.01490	0.01490	0.01540	0.01540
ACTUAL RIG CONDITIONS										
P3, PSIA	62.01	62.28	70.69	70.92	69.99	70.50	70.44	69.80	68.00	68.06
T3, F	483.0	481.7	352.4	357.6	412.9	410.1	493.3	492.6	482.3	483.3
W36, PPS	18.76	18.97	22.75	23.15	21.81	22.12	21.98	21.32	20.86	20.27
WFE, PPH	1043.	1024.	1136.	1137.	1130.	1132.	1132.	1134.	1135.	1120.
FAR4	0.01583	0.01537	0.01392	0.01366	0.01449	0.01432	0.01435	0.01480	0.01550	0.01573
HUM, GR/LB	175.2	174.2	13.6	11.0	51.7	51.2	13.0	10.1	174.6	177.5
EMISSION DATA, MEASURED										
CO, PPM	179.9	179.0	238.1	226.6	176.9	201.3	145.6	154.5	171.9	163.4
CO2, PCT	3.576	3.278	3.039	3.021	3.100	3.301	3.192	3.251	3.496	3.365
HC, PPM	1.0	1.6	13.1	8.2	2.5	2.3	1.3	1.0	0.7	1.3
NOX, PPM	33.2	33.7	39.1	38.1	41.1	39.8	53.9	56.4	34.4	34.4
EICO	10.05	10.90	15.61	14.94	11.39	12.17	9.11	9.50	9.83	9.70
EIHC	0.03	0.06	0.49	0.31	0.09	0.08	0.05	0.04	0.02	0.04
EINOX	3.05	3.37	4.21	4.13	4.35	3.96	5.54	5.70	3.23	3.36
SMOKE	3.5	1.9	2.8	3.7	2.6	2.9	3.6	1.8	3.8	0.5
FARGAS	0.01761	0.01613	0.01488	0.01488	0.01524	0.01625	0.01568	0.01598	0.01721	0.01655
EFF, PCT	99.75	99.73	99.58	99.61	99.72	99.70	99.77	99.77	99.76	99.76
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	10.05	10.90	15.61	14.94	11.39	12.17	9.11	9.50	9.83	9.70
EIHC	0.03	0.06	0.49	0.31	0.09	0.08	0.05	0.04	0.02	0.04
EINOX	3.05	3.37	4.21	4.13	4.35	3.95	5.53	5.71	3.24	3.37
SMOKE	3.5	1.9	2.8	3.7	2.6	2.8	3.6	1.8	3.9	0.5
EFF, PCT	99.76	99.74	99.59	99.62	99.73	99.71	99.78	99.77	99.77	99.77

CFM56 COMBUSTOR RIG DATA

CASE	B1	B2	B3	B4	B5	B6	B7	B8	B9	90
RDG	15	46	37	121	22	43	87	137	54	57
POINT	2A19	2B19	2A20	2B20	2A21	2B21	2A22	2B22	3A 1	3B 1
DATE	11/22/76	11/23/76	11/23/76	12/ 7/76	11/22/76	11/23/76	12/ 6/76	12/10/76	11/30/76	12/ 6/76
SIMULATED ENGINE CONDITIONS										
POWER	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	1.5IDL	APP	APP
FN, LBS	1784.	1784.	1735.	1735.	1719.	1719.	1649.	1649.	6466.	6466.
FNK, LBS	2054.	2054.	1997.	1997.	1979.	1979.	1899.	1899.	6600.	6600.
TAMB, F	19.0	19.0	59.0	59.0	105.0	105.0	105.0	105.0	19.0	19.0
PAMB, PSIA	12.763	12.763	12.763	12.763	12.763	12.763	12.763	12.763	14.398	14.398
HUM, GR/LB	14.0	14.0	52.5	52.5	14.0	14.0	175.0	175.0	14.0	14.0
P3, PSIA	57.15	57.15	56.55	56.55	56.61	56.61	55.24	55.24	138.56	138.56
T3, F	357.3	357.3	417.9	417.9	491.6	491.6	482.4	482.4	551.4	551.4
W36, PPS	18.37	18.37	17.69	17.69	17.25	17.25	16.76	16.76	40.97	40.97
WFE, PPH	943.	943.	939.	939.	942.	942.	929.	929.	2379.	2379.
FAR4	0.01430	0.01430	0.01490	0.01490	0.01520	0.01520	0.01530	0.01530	0.01620	0.01620
ACTUAL RIG CONDITIONS										
P3, PSIA	57.14	57.47	56.51	56.80	56.69	56.63	55.09	55.53	138.34	139.19
T3, F	357.8	358.9	413.8	412.1	494.6	492.2	480.0	477.9	547.0	553.7
W36, PPS	17.99	18.01	17.56	17.44	17.07	16.60	16.14	17.05	40.28	40.88
WFE, PPH	928.	931.	927.	931.	927.	930.	928.	917.	2378.	2420.
FAR4	0.01440	0.01438	0.01477	0.01495	0.01513	0.01558	0.01638	0.01531	0.01642	0.01648
HUM, GR/LB	12.3	8.6	50.8	53.7	12.6	7.9	176.8	169.9	9.2	13.2
EMISSION DATA, MEASURED										
CO, PPM	343.1	333.2	250.6	264.5	195.4	208.7	220.0	199.9	80.7	52.8
CO2, PCT	3.125	3.101	3.242	3.320	3.286	3.302	3.632	3.370	3.479	3.635
HC, PPM	22.3	17.1	5.4	5.2	1.8	2.0	1.5	2.2	1.6	2.8
NOX, PPM	35.6	34.8	39.1	37.9	50.4	51.7	34.5	32.0	82.3	79.9
EICO	21.80	21.34	15.40	15.87	11.87	12.61	12.09	11.84	4.65	2.92
EIHC	0.81	0.63	0.19	0.18	0.06	0.07	0.05	0.07	0.05	0.09
EINOX	3.71	3.66	3.94	3.73	5.03	5.13	3.12	3.11	7.79	7.24
SMOKE	3.2	2.4	2.7	2.3	2.3	2.9	2.5	0.	5.6	1.5
FARGAS	0.01546	0.01534	0.01599	0.01638	0.01617	0.01626	0.01791	0.01660	0.01708	0.01784
EFF, PCT	99.40	99.43	99.61	99.60	99.71	99.69	99.70	99.71	99.88	99.91
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	21.80	21.34	15.40	15.87	11.87	12.61	12.09	11.84	4.65	2.92
EIHC	0.81	0.63	0.19	0.18	0.06	0.07	0.05	0.07	0.05	0.09
EINOX	3.71	3.65	3.94	3.72	5.03	5.13	3.12	3.10	7.79	7.23
SMOKE	3.2	2.4	2.7	2.3	2.3	2.9	2.6	0.	5.6	1.5
EFF, PCT	99.41	99.44	99.62	99.61	99.72	99.70	99.71	99.72	99.89	99.92

CFM56 COMBUSTOR RIG DATA

CASE	91	92	93	94	95	96	97	98	99	100
RDG	58	104	59	98	60	105	61	106	82	103
POINT	3A 2	3B 2	3A 3	3B 3	3A 4	3B 4	3A 5	3B 5	3A 6	3B 6
DATE	12/ 6/76	12/ 7/76	12/ 6/76	12/ 6/76	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76
SIMULATED ENGINE CONDITIONS										
POWER	APP	APP	APP	APP	APP	APP	APP	APP	APP	APP
FN, LBS	6466.	6466.	6466.	6466.	6466.	6466.	6466.	6466.	6466.	6466.
FNK, LBS	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.
TAMB, F	39.0	39.0	59.0	59.0	85.0	85.0	105.0	105.0	39.0	39.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	35.0	35.0
P3, PSIA	138.81	138.81	138.97	138.97	139.17	139.17	139.36	139.36	138.80	138.80
T3, F	590.3	590.3	628.9	628.9	678.7	678.7	716.7	716.7	589.8	589.8
W36, PPS	40.40	40.40	39.84	39.84	39.17	39.17	38.69	38.69	40.36	40.36
WFE, PPH	2415.	2415.	2448.	2448.	2489.	2489.	2521.	2521.	2419.	2419.
FAR4	0.01660	0.01660	0.01710	0.01710	0.01770	0.01770	0.01810	0.01810	0.01670	0.01670
ACTUAL RIG CONDITIONS										
P3, PSIA	139.22	140.18	138.62	139.06	139.52	139.59	139.73	139.90	138.88	139.28
T3, F	590.1	591.9	625.3	626.4	676.0	678.3	707.8	719.2	587.4	593.2
W36, PPS	39.88	39.85	39.68	40.29	38.73	37.08	38.63	38.71	40.41	38.73
WFE, PPH	2458.	2427.	2459.	2467.	2531.	2508.	2533.	2539.	2418.	2432.
FAR4	0.01715	0.01697	0.01725	0.01705	0.01819	0.01884	0.01825	0.01827	0.01670	0.01752
HUM, GR/LB	11.6	19.9	14.3	16.9	13.3	20.0	13.0	20.8	33.1	33.0
EMISSION DATA, MEASURED										
CO, PPM	52.3	61.5	46.2	55.4	48.2	59.9	35.6	55.6	73.9	72.0
CO2, PCT	3.775	3.701	3.758	3.818	3.885	3.977	3.914	4.071	3.717	3.815
HC, PPM	1.5	0.2	1.3	0.	1.0	0.	1.0	0.3	0.2	0.
NOX, PPM	88.2	85.9	91.1	92.4	101.3	103.9	113.3	113.2	81.3	83.1
EICO	2.78	3.33	2.46	2.91	2.49	3.02	1.82	2.74	3.99	3.78
EIHC	0.04	0.01	0.04	0.	0.03	0.	0.03	0.01	0.01	0.
EINOX	7.35	7.65	7.98	7.97	8.59	8.61	9.54	9.16	7.20	7.17
SMOKE	1.7	2.5	0.3	3.2	0.3	1.7	1.9	2.3	1.7	2.6
FARGAS	0.01854	0.01818	0.01845	0.01876	0.01909	0.01955	0.01923	0.02002	0.01826	0.01875
EFF, PCT	99.91	99.91	99.92	99.92	99.92	99.92	99.95	99.93	99.90	99.90
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	2.78	3.33	2.46	2.91	2.49	3.02	1.82	2.74	3.99	3.78
EIHC	0.04	0.01	0.04	0.	0.03	0.	0.03	0.01	0.01	0.
EINOX	7.34	7.62	7.99	7.97	8.58	8.60	9.53	9.15	7.20	7.16
SMOKE	1.6	2.5	0.3	3.2	0.3	1.7	1.9	2.2	1.7	2.6
EFF, PCT	99.93	99.92	99.94	99.93	99.94	99.93	99.95	99.94	99.91	99.91

CFM56 COMBUSTOR RIG DATA

CASE	101	102	103	104	105	106	107	108	109	110
RDG	78	99	77	112	71	107	79	100	72	110
POINT	3A 7	3B 7	3C 8	3D 8	3A 9	3B 9	3A10	3B10	3A11	3B11
DATE	12/ 6/76	12/ 6/76	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76	12/ 6/76	12/ 6/76	12/ 6/76	12/ 7/76
SIMULATED ENGINE CONDITIONS										
POWER	APP	APP	APP	APP	APP	APP	APP	APP	APP	APP
FN, LBS	6466.	6466.	6466.	6466.	6466.	6466.	6466.	6466.	6466.	6466.
FNK, LBS	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.
TAMB, F	59.0	59.0	85.0	85.0	105.0	105.0	59.0	59.0	85.0	85.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	52.5	52.5	52.5	52.5	52.5	52.5	70.0	70.0	105.0	105.0
P3, PSIA	138.94	138.94	139.15	139.15	139.33	139.33	138.93	138.93	139.12	139.12
T3, F	627.8	627.8	677.5	677.5	715.5	715.5	627.3	627.3	675.9	675.9
W36, PPS	39.77	39.77	39.10	39.10	38.62	38.62	39.74	39.74	39.01	39.01
WFE, PPH	2455.	2455.	2497.	2497.	2529.	2529.	2458.	2458.	2508.	2508.
FAR4	0.01730	0.01730	0.01790	0.01790	0.01830	0.01830	0.01740	0.01740	0.01810	0.01810
ACTUAL RIG CONDITIONS										
P3, PSIA	138.83	139.02	139.10	139.93	139.25	139.62	139.28	139.16	139.35	139.68
T3, F	623.8	627.6	675.1	677.9	715.5	718.2	625.8	628.9	678.2	675.9
W36, PPS	40.21	40.04	38.69	37.91	38.45	38.66	40.50	40.39	38.39	39.16
WFE, PPH	2492.	2498.	2493.	2506.	2542.	2521.	2523.	2519.	2512.	2530.
FAR4	0.01734	0.01746	0.01802	0.01850	0.01850	0.01825	0.01748	0.01750	0.01845	0.01822
HUM, GR/LB	52.6	53.0	48.4	51.4	54.1	51.9	68.9	70.0	106.3	105.9
EMISSION DATA, MEASURED										
CO, PPM	73.6	57.4	60.9	59.8	46.8	51.8	62.8	65.3	56.3	52.1
CO2, PCT	3.837	3.888	3.911	3.954	4.039	4.080	3.851	3.937	4.039	4.050
HC, PPM	0.3	0.	0.	0.	0.	0.	0.2	0.2	0.	0.2
NOX, PPM	81.7	83.1	95.4	94.8	116.7	103.0	78.5	79.2	89.9	81.8
EICO	3.85	2.96	3.12	3.03	2.32	2.55	3.27	3.32	2.79	2.58
EIHC	0.01	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	7.01	7.04	8.03	7.90	9.52	8.31	6.71	6.63	7.33	6.65
SMOKE	1.3	1.8	2.3	6.0	2.6	3.6	1.5	1.7	1.7	3.7
FARGAS	0.01886	0.01911	0.01922	0.01944	0.01986	0.02006	0.01893	0.01936	0.01986	0.01991
EFF, PCT	99.90	99.92	99.92	99.92	99.94	99.93	99.91	99.91	99.92	99.93
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	3.85	2.96	3.12	3.03	2.32	2.55	3.27	3.32	2.79	2.58
EIHC	0.01	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	7.01	7.04	8.03	7.88	9.52	8.30	6.70	6.63	7.33	6.64
SMOKE	1.3	1.8	2.3	6.0	2.6	3.6	1.5	1.7	1.7	3.7
EFF, PCT	99.91	99.93	99.93	99.93	99.95	99.94	99.92	99.92	99.93	99.94

CFM56 COMBUSTOR RIG DATA

CASE	111	112	113	114	115	116	117	118	119	120
RDG	69	108	76	111	67	109	55	63	80	101
POINT	3B12	3C12	3B13	3C13	3A14	3B14	3A15	3B15	3A16	3B16
DATE	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76	11/30/76	12/ 6/76	12/ 6/76	12/ 6/76
SIMULATED ENGINE CONDITIONS										
POWER	APP	APP	APP	APP	APP	APP	APP	APP	APP	APP
FN, LBS	6466.	6466.	6466.	6466.	6466.	6466.	7121.	7121.	7121.	7121.
FNK, LBS	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.
TAMB, F	105.0	105.0	85.0	85.0	105.0	105.0	19.0	19.0	59.0	59.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	15.856	15.856	15.856	15.856
HUM, GR/LB	105.0	105.0	175.0	175.0	175.0	175.0	14.0	14.0	52.5	52.5
P3, PSIA	139.31	139.31	139.07	139.07	139.26	139.26	152.62	152.62	153.02	153.02
T3, F	713.8	713.8	673.9	673.9	711.7	711.7	551.4	551.4	627.8	627.8
W36, PPS	38.53	38.53	38.89	38.89	38.41	38.41	45.14	45.14	43.82	43.82
WFE, PPH	2539.	2539.	2521.	2521.	2553.	2553.	2616.	2616.	2699.	2699.
FAR4	0.01860	0.01860	0.01850	0.01850	0.01890	0.01890	0.01610	0.01610	0.01720	0.01720
ACTUAL RIG CONDITIONS										
P3, PSIA	139.05	140.34	138.69	139.37	139.54	139.47	151.63	153.78	152.57	153.52
T3, F	715.6	716.1	675.1	675.5	714.7	709.8	550.0	552.7	626.5	627.9
W36, PPS	38.02	39.46	38.34	38.79	38.24	38.67	44.07	45.13	42.99	43.05
WFE, PPH	2558.	2561.	2528.	2532.	2567.	2571.	2628.	2667.	2709.	2706.
FAR4	0.01897	0.01829	0.01877	0.01858	0.01914	0.01893	0.01658	0.01645	0.01763	0.01759
HUM, GR/LB	106.0	102.0	172.1	174.9	184.3	174.0	8.5	12.5	52.6	53.7
EMISSION DATA, MEASURED										
CO, PPM	49.2	50.3	66.8	59.6	45.6	60.9	59.4	61.8	53.0	52.6
CO2, PCT	4.158	4.141	3.992	4.078	4.069	4.235	3.532	3.693	3.764	3.844
HC, PPM	0.	0.2	0.3	0.	0.3	0.3	1.2	0.5	0.2	0.3
NOX, PPM	98.4	88.3	67.0	65.6	69.6	70.0	84.7	80.6	85.2	86.3
EICO	2.37	2.44	3.35	2.93	2.25	2.88	3.37	3.35	2.82	2.75
EIHC	0.	0.	0.01	0.	0.01	0.01	0.04	0.02	0.	0.01
EINOX	7.80	7.02	5.53	5.30	5.64	5.44	7.90	7.18	7.46	7.39
SMOKE	0.3	3.0	1.5	2.4	2.6	3.1	2.6	0.3	0.5	1.6
FARGAS	0.02046	0.02037	0.01963	0.02006	0.02001	0.02085	0.01733	0.01813	0.01848	0.01889
EFF, PCT	99.03	99.03	99.01	99.02	99.03	99.02	99.01	99.01	99.02	99.03
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	2.37	2.44	3.35	2.93	2.25	2.88	3.37	3.35	2.82	2.75
EIHC	0.	0.	0.01	0.	0.01	0.01	0.04	0.02	0.	0.01
EINOX	7.81	7.00	5.54	5.30	5.64	5.44	7.92	7.16	7.47	7.38
SMOKE	0.3	2.9	1.5	2.4	2.6	3.1	2.6	0.3	0.5	1.6
EFF, PCT	99.04	99.04	99.02	99.03	99.05	99.03	99.02	99.02	99.03	99.03

CFM56 COMBUSTOR RIG DATA

CASE	121	122	123	124	125	126	127	128	129	130
RDG	62	114	70	113	56	64	81	102	65	115
POINT	3A17	3B17	3A18	3B18	3A19	3B19	3A20	3B20	3A21	3B21
DATE	12/ 6/76	12/ 7/76	12/ 6/76	12/ 7/76	11/30/76	12/ 6/76	12/ 6/76	12/ 6/76	12/ 6/76	12/ 7/76
SIMULATED ENGINE CONDITIONS										
POWER	APP	APP	APP	APP	APP	APP	APP	APP	APP	APP
FN, LBS	7121.	7121.	7121.	7121.	5732.	5732.	5732.	5732.	5732.	5732.
FNK, LBS	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.	6600.
TAMB, F	105.0	105.0	105.0	105.0	19.0	19.0	59.0	59.0	105.0	105.0
PAMB, PSIA	15.856	15.856	15.856	15.856	12.763	12.763	12.763	12.763	12.763	12.763
HUM, GR/LB	14.0	14.0	175.0	175.0	14.0	14.0	52.5	52.5	14.0	14.0
P3, PSIA	153.48	153.48	153.37	153.37	122.83	122.83	123.14	123.14	123.49	123.49
T3, F	716.7	716.7	711.7	711.7	551.4	551.4	627.8	627.8	716.9	716.9
W36, PPS	42.63	42.63	42.33	42.33	36.29	36.29	35.22	35.22	34.25	34.25
WFE, PPH	2771.	2771.	2807.	2807.	2113.	2113.	2182.	2182.	2241.	2241.
FAR4	0.01810	0.01810	0.01890	0.01890	0.01620	0.01620	0.01730	0.01730	0.01820	0.01820
ACTUAL RIG CONDITIONS										
P3, PSIA	153.16	154.04	153.80	153.98	122.86	122.78	122.91	124.11	123.54	123.85
T3, F	714.0	717.1	715.0	713.6	553.7	552.0	625.6	626.6	712.7	718.3
W36, PPS	42.05	42.27	41.98	42.30	36.47	35.57	34.60	35.29	34.36	34.28
WFE, PPH	2774.	2789.	2832.	2818.	2117.	2124.	2183.	2200.	2258.	2252.
FAR4	0.01839	0.01837	0.01919	0.01896	0.01615	0.01662	0.01766	0.01744	0.01829	0.01829
HUM, GR/LB	12.8	17.7	170.3	172.1	9.9	14.1	54.9	51.8	15.0	18.7
EMISSION DATA, MEASURED										
CO, PPM	33.0	55.3	51.3	107.8	70.6	77.8	67.8	64.0	45.9	61.7
CO2, PCT	4.007	4.059	4.114	4.135	3.353	3.669	3.785	3.805	3.954	4.044
HC, PPM	0.5	0.2	0.	0.3	0.8	0.5	0.	0.2	0.5	0.2
NOX, PPM	120.4	124.5	86.8	78.6	80.4	74.8	80.2	81.6	110.2	110.7
EICO	1.65	2.73	2.50	5.22	4.22	4.25	3.59	3.37	2.33	3.06
EIHC	0.01	0.	0.	0.01	0.03	0.02	0.	0.	0.01	0.
EINOX	9.90	10.10	6.95	5.93	7.90	6.71	6.98	7.07	9.18	9.02
SMOKE	2.2	3.1	3.6	6.1	0.3	1.6	3.1	1.3	1.0	3.3
FARGAS	0.01969	0.01996	0.02024	0.02037	0.01645	0.01802	0.01860	0.01870	0.01943	0.01989
EFF, PCT	99.95	99.93	99.93	99.87	99.89	99.89	99.91	99.91	99.94	99.92
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	1.65	2.73	2.50	5.22	4.22	4.25	3.59	3.37	2.33	3.06
EIHC	0.01	0.	0.	0.01	0.03	0.02	0.	0.	0.01	0.
EINOX	9.91	10.09	6.94	5.92	7.90	6.71	6.98	7.05	9.18	9.01
SMOKE	2.2	3.1	3.6	6.1	0.3	1.6	3.1	1.3	1.0	3.3
EFF, PCT	99.96	99.94	99.94	99.88	99.90	99.90	99.92	99.92	99.94	99.93

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CFM56 COMBUSTOR RIG DATA

CASE	131	132	133	134	135	136	137	138	139	140
RDG	66	116	153	189	154	188	157	184	160	175
POINT	3A22	3B22	4A 1	4B 1	4A 2	4B 2	4A 3	4B 3	4A 4	4B 4
DATE	12/ 6/76	12/ 7/76	12/13/76	12/13/76	12/13/76	12/13/76	12/13/76	12/13/76	12/13/76	12/13/76
SIMULATED ENGINE CONDITIONS										
POWER	APP	APP	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI
FN, LBS	5732.	5732.	18321.	18321.	18321.	18321.	18321.	18321.	18321.	18321.
FNK, LBS	6600.	6600.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.
TAMB, F	105.0	105.0	19.0	19.0	39.0	39.0	59.0	59.0	85.0	85.0
PAMB, PSIA	12.763	12.763	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	175.0	175.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
P3, PSIA	123.40	123.40	301.78	301.78	302.02	302.02	302.14	302.14	301.90	301.90
T3, F	711.8	711.8	799.0	799.0	845.6	845.6	891.5	891.5	949.9	949.9
W36, PPS	34.01	34.01	78.33	78.33	77.17	77.17	76.05	76.05	74.51	74.51
WFE, PPH	2270.	2270.	6468.	6468.	6586.	6586.	6696.	6696.	6859.	6859.
FAR4	0.01900	0.01900	0.02300	0.02300	0.02380	0.02380	0.02450	0.02450	0.02560	0.02560
ACTUAL RIG CONDITIONS										
P3, PSIA	124.06	123.64	166.35	166.30	167.08	166.26	166.55	165.95	166.70	166.92
T3, F	715.7	712.6	804.5	792.7	842.7	851.5	888.9	896.3	949.9	946.4
W36, PPS	34.42	33.63	41.35	43.74	43.00	41.86	42.02	41.97	40.89	40.43
WFE, PPH	2288.	2257.	3597.	3599.	3665.	3640.	3734.	3745.	3816.	3813.
FAR4	0.01893	0.01910	0.02820	0.02290	0.02371	0.02420	0.02473	0.02483	0.02597	0.02624
HUM, GR/LB	175.1	174.6	10.6	12.1	11.0	12.9	11.4	10.9	12.1	12.1
EMISSION DATA, MEASURED										
CO, PPM	34.0	58.2	60.1	66.5	49.8	68.0	58.5	95.8	102.5	87.9
CO2, PCT	3.990	4.171	5.062	4.975	5.204	5.130	5.460	5.233	5.584	5.654
HC, PPM	0.3	0.	0.2	0.	0.	0.	0.	0.	0.	0.
NOX, PPM	68.1	70.0	180.0	164.9	202.4	193.0	226.6	220.3	265.9	270.2
EICO	1.71	2.80	2.38	2.68	1.92	2.66	2.15	3.67	3.68	3.12
EIHC	0.01	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	5.62	5.53	11.72	10.92	12.82	12.40	13.67	13.86	15.68	15.74
SMOKE	0.7	3.0	4.8	4.9	4.6	2.6	2.7	3.2	1.5	4.1
FARGAS	0.01961	0.02053	0.02562	0.02458	0.02573	0.02536	0.02703	0.02590	0.02768	0.02803
EFF, PCT	99.95	99.92	99.94	99.93	99.95	99.93	99.94	99.91	99.91	99.92
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	1.71	2.80	2.38	2.68	1.92	2.66	2.15	3.67	3.68	3.12
EIHC	0.01	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	5.61	5.53	14.61	13.61	15.96	15.46	17.04	17.30	19.53	19.60
SMOKE	0.7	3.0	11.7	12.1	11.1	6.4	6.6	7.7	3.5	9.9
EFF, PCT	99.96	99.93	99.94	99.94	99.96	99.94	99.95	99.91	99.91	99.93

CFM56 COMBUSTOR RIG DATA

CASE	141	142	143	144	145	146	147	148	149	150
RDG	161	172	142	187	144	185	176	231	171	233
POINT	4A 5	4B 5	4A 6	4B 6	4A 7	4B 7	4B 8	4C 8	4B 9	4C 9
DATE	12/13/76	12/13/76	12/10/76	12/13/76	12/10/76	12/13/76	12/13/76	12/14/76	12/13/76	12/14/76
SIMULATED ENGINE CONDITIONS										
POWER	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI
FN, LBS	18321.	18321.	18321.	18321.	18321.	18321.	18321.	18321.	18321.	18321.
FNK, LBS	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.
TAMB, F	105.0	105.0	39.0	39.0	59.0	59.0	85.0	85.0	105.0	105.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	14.0	14.0	35.0	35.0	52.5	52.5	52.5	52.5	52.5	52.5
P3, PSIA	301.84	301.84	301.96	301.96	302.04	302.04	301.83	301.83	301.79	301.79
T3, F	994.4	994.4	844.7	844.7	889.7	889.7	948.0	948.0	992.5	992.5
W36, PPS	73.42	73.42	77.09	77.09	75.91	75.91	74.38	74.38	73.30	73.30
WFE, PPH	6989.	6989.	6597.	6597.	6717.	6717.	6880.	6880.	7010.	7010.
FAR4	0.02650	0.02650	0.02390	0.02390	0.02480	0.02480	0.02590	0.02590	0.02680	0.02680
ACTUAL RIG CONDITIONS										
P3, PSIA	166.57	166.12	166.20	165.95	166.41	166.05	166.78	166.28	165.28	167.42
T3, F	992.0	991.4	858.5	846.8	883.5	893.6	943.5	944.3	990.4	987.2
W36, PPS	40.35	40.03	42.72	41.46	41.17	41.12	40.87	40.85	40.61	40.64
WFE, PPH	3878.	3872.	3647.	3663.	3709.	3738.	3824.	3816.	3887.	3907.
FAR4	0.02675	0.02691	0.02383	0.02466	0.02520	0.02545	0.02619	0.02614	0.02678	0.02691
HUM, GR/LB	12.0	11.6	33.7	34.1	50.0	54.5	53.1	51.7	51.6	52.6
EMISSION DATA, MEASURED										
CO, PPM	89.5	101.3	46.0	67.5	47.2	65.1	77.8	56.2	109.2	60.2
CO2, PCT	5.707	5.620	5.144	5.194	5.381	5.247	5.702	5.573	5.606	5.692
HC, PPM	0.2	0.	0.3	0.	0.	0.	0.	0.	0.3	0.
NOX, PPM	320.5	302.4	184.8	182.4	204.8	195.9	238.4	242.8	263.5	276.1
EICO	3.14	3.61	1.80	2.61	1.76	2.49	2.74	2.02	3.91	2.12
EIHC	0.	0.	0.01	0.	0.	0.	0.	0.	0.01	0.
EINOX	18.50	17.71	11.84	11.57	12.54	12.30	13.77	14.36	15.48	15.98
SMOKE	2.5	3.9	3.9	1.7	4.3	1.7	2.4	1.9	2.1	2.0
FARGAS	0.02830	0.02787	0.02542	0.02569	0.02662	0.02595	0.02827	0.02760	0.02780	0.02821
EFF, PCT	99.92	99.91	99.95	99.93	99.95	99.93	99.93	99.94	99.90	99.94
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	3.14	3.61	1.80	2.61	1.76	2.49	2.74	2.02	3.91	2.12
EIHC	0.	0.	0.01	0.	0.	0.	0.	0.	0.01	0.
EINOX	23.05	22.09	14.77	14.44	15.63	15.35	17.15	17.90	19.34	19.87
SMOKE	6.2	9.5	9.6	4.1	10.6	4.1	5.8	4.7	5.3	4.7
EFF, PCT	99.93	99.92	99.96	99.94	99.96	99.94	99.94	99.95	99.91	99.95

CFM56 COMBUSTOR RIG DATA

CASE	151	152	153	154	155	156	157	158	159	160
RDG	143	186	147	177	150	173	146	178	149	174
POINT	4A10	4B10	4A11	4B11	4A12	4B12	4A13	4B13	4A14	4B14
DATE	12/10/76	12/13/76	12/10/76	12/13/76	12/10/76	12/13/76	12/10/76	12/13/76	12/10/76	12/13/76
SIMULATED ENGINE CONDITIONS										
POWER	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI
FN, LBS	18321.	18321.	18321.	18321.	19321.	19321.	18321.	18321.	18321.	18321.
FNK, LBS	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.
TAMB, F	59.0	59.0	85.0	85.0	105.0	105.0	85.0	85.0	105.0	105.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	70.0	70.0	105.0	105.0	105.0	105.0	175.0	175.0	175.0	175.0
P3, PSIA	301.99	301.99	301.76	301.76	301.73	301.73	301.68	301.68	301.65	301.65
T3, F	888.9	888.9	945.6	945.6	990.0	990.0	942.5	942.5	986.7	986.7
W36, PPS	75.85	75.85	74.22	74.22	73.14	73.14	74.01	74.01	72.93	72.93
WFE, PPH	6726.	6726.	6907.	6907.	7039.	7039.	6943.	6943.	7076.	7076.
FAR4	0.02490	0.02490	0.02620	0.02620	0.02710	0.02710	0.02670	0.02670	0.02760	0.02760
ACTUAL RIG CONDITIONS										
P3, PSIA	166.17	166.58	165.52	166.50	166.29	166.05	165.24	166.81	165.87	166.40
T3, F	883.8	891.2	943.2	942.3	988.4	992.1	944.6	941.2	989.1	989.3
W36, PPS	42.27	41.78	40.62	40.09	39.92	40.33	40.36	41.70	40.92	40.33
WFE, PPH	3688.	3708.	3824.	3818.	3873.	3919.	3845.	3862.	3920.	3937.
FAR4	0.02447	0.02517	0.02654	0.02686	0.02736	0.02740	0.02712	0.02636	0.02725	0.02779
HUM, GR/LB	67.3	69.0	104.5	106.8	105.1	104.4	174.9	172.4	170.0	173.7
EMISSION DATA, MEASURED										
CO, PPM	45.6	64.3	59.1	75.9	82.0	80.9	62.9	65.9	90.6	118.6
CO2, PCT	5.255	5.353	5.680	5.687	5.734	5.577	5.704	5.620	5.788	5.755
HC, PPM	0.	0.	0.	0.	0.2	0.2	0.	0.2	0.	0.
NOX, PPM	192.7	185.4	234.9	206.5	266.4	225.3	170.0	168.9	216.2	194.9
EICO	1.74	2.41	2.09	2.67	2.87	2.91	2.21	2.35	3.14	4.13
EIHC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	12.09	11.41	13.63	11.96	15.31	13.31	9.82	9.90	12.30	11.15
SMOKE	5.8	4.1	5.0	4.2	7.8	3.2	6.7	4.7	4.5	3.9
FARGAS	0.02598	0.02649	0.02815	0.02820	0.02843	0.02764	0.02828	0.02785	0.02872	0.02856
EFF, PCT	99.05	99.03	99.04	99.03	99.02	99.02	99.04	99.03	99.02	99.89
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	1.74	2.41	2.09	2.67	2.87	2.91	2.21	2.35	3.14	4.13
EIHC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	15.08	14.22	17.02	14.90	19.09	16.60	12.27	12.33	15.35	13.90
SMOKE	10.1	10.1	12.3	10.1	19.0	7.8	16.6	11.5	11.0	9.5
EFF, PCT	99.06	99.04	99.05	99.04	99.03	99.03	99.05	99.05	99.03	99.90

CFM56 COMBUSTOR RIG DATA

CASE	161	162	163	164	165	166	167	168	169	170
RDG	217	243	221	242	211	232	212	237	152	190
POINT	4A15	4B15	4A16	4B16	4A17	4B17	4A18	4B18	4A19	4B19
DATE	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/13/76	12/13/76
SIMULATED ENGINE CONDITIONS										
POWER	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI	CLI
FN, LBS	20176.	20176.	20176.	20176.	20176.	20176.	20176.	20176.	16240.	16240.
FNK, LBS	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.	18700.
TAMB, F	19.0	19.0	59.0	59.0	105.0	105.0	105.0	105.0	19.0	19.0
PAMB, PSIA	15.856	15.856	15.856	15.856	15.856	15.856	15.856	15.856	12.763	12.763
HUM, GR/LB	14.0	14.0	52.5	52.5	14.0	14.0	175.0	175.0	14.0	14.0
P3, PSIA	332.36	332.36	332.36	332.36	332.52	332.52	332.30	332.30	267.47	267.47
T3, F	799.1	799.1	889.7	889.7	994.4	994.4	986.7	986.7	799.0	799.0
W36, PPS	86.30	86.30	83.64	83.64	80.93	80.93	80.39	80.39	69.39	69.39
WFE, PPH	7115.	7115.	7388.	7388.	7681.	7681.	7777.	7777.	5743.	5743.
FAR4	0.02290	0.02290	0.02470	0.02470	0.02640	0.02640	0.02750	0.02750	0.02300	0.02300
ACTUAL RIG CONDITIONS										
P3, PSIA	183.50	182.43	183.71	183.82	181.58	183.98	182.03	184.07	147.39	147.69
T3, F	791.3	793.2	885.2	887.1	983.9	988.5	982.3	981.5	800.5	794.4
W36, PPS	47.21	47.69	46.74	45.81	44.77	45.05	44.32	43.56	38.07	38.23
WFE, PPH	3939.	3951.	4105.	4109.	4278.	4269.	4299.	4283.	3198.	3182.
FAR4	0.02325	0.02306	0.02457	0.02510	0.02659	0.02638	0.02761	0.02800	0.02338	0.02316
HUM, GR/LB	22.0	15.0	50.0	53.6	13.3	15.0	172.9	175.9	12.1	12.6
EMISSION DATA, MEASURED										
CO, PPM	35.3	58.3	38.2	60.1	128.2	54.6	125.4	75.0	86.6	89.5
CO2, PCT	5.080	5.261	5.267	5.611	5.596	5.712	5.779	5.770	4.978	4.938
HC, PPM	0.3	0.	0.	0.	0.	0.	0.	0.	0.	0.
NOX, PPM	176.9	180.8	211.8	214.5	297.9	314.9	196.8	207.5	178.7	158.5
EICO	1.39	2.22	1.46	2.15	4.59	1.92	4.35	2.61	3.49	3.63
EIHC	0.01	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	11.48	11.32	13.26	12.60	17.52	18.17	11.21	11.85	11.82	10.57
SMOKE	6.8	6.4	4.1	5.2	4.2	3.7	4.4	2.6	10.3	3.0
FARGAS	0.02509	0.02602	0.02604	0.02780	0.02776	0.02831	0.02869	0.02861	0.02460	0.02440
EFF, PCT	99.96	99.94	99.96	99.94	99.88	99.95	99.89	99.93	99.91	99.91
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	1.39	2.22	1.46	2.15	4.59	1.92	4.35	2.61	3.49	3.63
EIHC	0.01	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	14.30	14.13	16.51	15.69	21.92	22.62	14.01	14.74	14.74	13.17
SMOKE	16.5	15.6	10.0	15.0	10.3	9.0	10.9	6.3	25.1	7.3
EFF, PCT	99.97	99.95	99.97	99.95	99.89	99.96	99.90	99.94	99.92	99.92

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CFM56 COMBUSTOR RIG DATA

CASE	171	172	173	174	175	176	177	178	179	180
RDG	145	222	162	195	194	198	155	218	158	224
POINT	4A20	4C20	4A21	4B21	4A22	4B22	5A 1	5C 1	5A 2	5D 2
DATE	12/10/76	12/14/76	12/13/76	12/13/76	12/13/76	12/14/76	12/13/76	12/14/76	12/13/76	12/14/76
SIMULATED ENGINE CONDITIONS										
POWER	CLI	CLI	CLI	CLI	CLI	CLI	T/O	T/O	T/O	T/O
FN, LBS	16240.	16240.	16240.	16240.	16240.	16240.	21554.	21554.	21554.	21554.
FNK, LBS	18700.	18700.	18700.	18700.	18700.	18700.	22000.	22000.	22000.	22000.
TAMB, F	59.0	59.0	105.0	105.0	105.0	105.0	19.0	19.0	39.0	39.0
PAMB, PSIA	12.763	12.763	12.763	12.763	12.763	12.763	14.398	14.398	14.398	14.398
HUM, GR/LB	52.5	52.5	14.0	14.0	175.0	175.0	14.0	14.0	14.0	14.0
P3, PSIA	267.70	267.70	267.45	267.45	267.28	267.28	343.07	343.07	343.53	343.53
T3, F	889.8	889.8	994.4	994.4	986.7	986.7	847.8	847.8	895.9	895.9
W36, PPS	67.23	67.23	65.00	65.00	64.57	64.57	87.02	87.02	85.77	85.77
WFE, PPH	5968.	5968.	6211.	6211.	6289.	6289.	7664.	7664.	7810.	7810.
FAR4	0.02480	0.02480	0.02660	0.02660	0.02770	0.02770	0.02450	0.02450	0.02530	0.02530
ACTUAL RIG CONDITIONS										
P3, PSIA	146.77	146.46	148.20	149.07	147.93	146.87	172.48	173.06	172.60	171.74
T3, F	883.1	890.2	994.0	991.7	980.3	975.9	847.4	848.6	892.9	900.5
W36, PPS	36.98	37.06	35.59	35.12	36.45	35.42	43.94	44.78	42.37	42.79
WFE, PPH	3316.	3316.	3451.	3477.	3512.	3517.	3883.	3871.	3956.	3945.
FAR4	0.02509	0.02503	0.02608	0.02754	0.02741	0.02828	0.02459	0.02409	0.02598	0.02566
HUM, GR/LB	49.4	50.9	12.7	12.1	168.5	178.0	11.0	21.8	10.8	15.4
EMISSION DATA, MEASURED										
CO, PPM	46.7	47.4	100.0	104.5	91.6	115.2	47.0	37.4	61.2	47.9
CO2, PCT	5.390	5.388	5.606	5.659	5.784	5.961	5.361	5.207	5.702	5.512
HC, PPM	0.	0.	0.	0.	0.	0.	0.	0.3	0.	0.
NOX, PPM	196.8	199.5	298.8	290.0	178.9	183.0	206.2	206.7	239.5	240.8
EICO	1.74	1.76	3.58	3.70	3.17	3.87	1.76	1.44	2.15	1.75
EIHC	0.	0.	0.	0.	0.	0.	0.	0.01	0.	0.
EINOX	12.04	12.20	17.55	16.87	10.19	10.11	12.68	13.08	13.84	14.40
SMOKE	2.4	2.3	3.2	3.0	3.5	3.7	6.1	3.3	3.2	3.3
FARGAS	0.02667	0.02666	0.02779	0.02806	0.02870	0.02961	0.02652	0.02574	0.02826	0.02729
EFF, PCT	99.95	99.95	99.91	99.90	99.92	99.90	99.95	99.96	99.94	99.95
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	1.74	1.76	3.58	3.70	3.17	3.87	1.76	1.44	2.15	1.75
EIHC	0.	0.	0.	0.	0.	0.	0.	0.01	0.	0.
EINOX	15.04	15.25	21.83	20.94	12.68	12.62	16.35	16.85	17.85	18.61
SMOKE	6.0	5.8	7.6	7.2	8.5	9.1	17.0	9.1	9.0	9.3
EFF, PCT	99.96	99.96	99.92	99.91	99.93	99.91	99.96	99.97	99.95	99.96

CFM56 COMBUSTOR RIG DATA

CASE	181	182	183	184	185	186	187	188	189	190
RDG	159	181	202	235	164	238	182	223	180	225
POINT	5A 3	5B 3	5B 4	5C 4	5A 5	5C 5	5A 6	5C 6	5A 7	5C 7
DATE	12/13/76	12/13/76	12/14/76	12/14/76	12/13/76	12/14/76	12/13/76	12/14/76	12/13/76	12/14/76
SIMULATED ENGINE CONDITIONS										
POWER	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
FN, LBS	21554.	21554.	21554.	21554.	21554.	21554.	21554.	21554.	21554.	21554.
FNK, LBS	22000.	22000.	22000.	22000.	22000.	22000.	22000.	22000.	22000.	22000.
TAMB, F	59.0	59.0	85.0	85.0	105.0	105.0	39.0	39.0	59.0	59.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	14.0	14.0	14.0	14.0	14.0	14.0	35.0	35.0	52.5	52.5
P3, PSIA	343.42	343.42	343.19	343.19	343.06	343.06	343.47	343.47	343.31	343.31
T3, F	942.8	942.8	1002.9	1002.9	1048.8	1048.8	894.9	894.9	940.8	940.8
W36, PPS	84.40	84.40	82.70	82.70	81.47	81.47	85.67	85.67	84.25	84.25
WFE, PPH	7965.	7965.	8168.	8168.	8326.	8326.	7824.	7824.	7989.	7989.
FAR0	0.02630	0.02630	0.02750	0.02750	0.02840	0.02840	0.02555	0.02555	0.02650	0.02650
ACTUAL RIG CONDITIONS										
P3, PSIA	171.95	172.48	170.76	171.20	171.47	173.46	171.72	170.32	171.96	172.05
T3, F	939.4	938.8	999.4	1000.0	1047.1	1043.6	894.8	899.2	940.6	937.4
W36, PPS	41.59	42.52	41.56	42.04	40.27	41.35	42.07	43.03	42.24	42.71
WFE, PPH	4033.	4017.	4104.	4120.	4186.	4198.	3946.	3950.	4033.	4033.
FAR0	0.02698	0.02628	0.02748	0.02729	0.02892	0.02827	0.02619	0.02562	0.02672	0.02642
HUM, GR/LB	11.1	10.0	13.7	16.3	10.4	15.5	38.3	34.0	51.5	50.9
EMISSION DATA, MEASURED										
CO, PPM	93.6	77.7	87.2	61.0	111.2	71.4	77.8	47.8	77.0	53.2
CO2, PCT	5.887	5.606	5.702	5.843	6.260	5.902	5.587	5.534	5.611	5.630
HC, PPM	0.	0.	0.	0.	0.	0.3	0.	0.	0.	0.
NOX, PPM	275.0	260.7	308.9	325.1	388.9	373.7	216.1	225.5	234.8	243.9
EICO	3.19	2.78	3.07	2.09	3.56	2.42	2.79	1.73	2.75	1.89
EIHC	0.	0.	0.	0.	0.	0.01	0.	0.	0.	0.
EINOX	15.39	15.32	17.84	18.34	20.46	20.86	12.74	13.43	13.79	14.28
SMOKE	3.4	4.3	2.7	2.9	4.4	6.7	4.9	4.6	4.9	3.7
FARGAS	0.02922	0.02778	0.02827	0.02898	0.03114	0.02929	0.02769	0.02740	0.02781	0.02789
EFF, PCT	99.92	99.93	99.92	99.94	99.91	99.93	99.93	99.95	99.93	99.95
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	3.19	2.78	3.07	2.09	3.56	2.42	2.79	1.73	2.75	1.89
EIHC	0.	0.	0.	0.	0.	0.01	0.	0.	0.	0.
EINOX	19.88	19.77	23.10	23.72	26.44	26.85	16.47	17.41	17.81	18.44
SMOKE	0.5	12.2	7.7	8.4	12.3	18.7	13.9	13.2	13.8	10.4
EFF, PCT	99.93	99.94	99.93	99.95	99.92	99.94	99.93	99.96	99.94	99.96

CFM56 COMBUSTOR RIG DATA

CASE	191	192	193	194	195	196	197	198	199	200
RDG	168	203	200	239	179	226	204	234	201	240
POINT	5A A	5B A	5B 9	5C 9	5A10	5C10	5B11	5C11	5B12	5C12
DATE	12/13/76	12/14/76	12/14/76	12/14/76	12/13/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76
SIMULATED ENGINE CONDITIONS										
POWER	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
FN, LBS	21554.	21554.	21554.	21554.	21554.	21554.	21554.	21554.	21554.	21554.
FNK, LBS	22000.	22000.	22000.	22000.	22000.	22000.	22000.	22000.	22000.	22000.
TAMB, F	85.0	85.0	105.0	105.0	59.0	59.0	85.0	85.0	105.0	105.0
PAMB, PSIA	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398	14.398
HUM, GR/LB	52.5	52.5	52.5	52.5	70.0	70.0	105.0	105.0	105.0	105.0
P3, PSIA	343.08	343.08	342.97	342.97	343.25	343.25	342.93	342.93	342.85	342.85
T3, F	1000.9	1000.9	1046.7	1046.7	940.0	940.0	998.2	998.2	1044.0	1044.0
W36, PPS	82.55	82.55	81.33	81.33	84.18	84.18	82.35	82.35	81.14	81.14
WFE, PPH	8192.	8192.	8349.	8349.	8000.	8000.	8225.	8225.	8382.	8382.
FAR4	0.02780	0.02780	0.02870	0.02870	0.02670	0.02670	0.02820	0.02820	0.02910	0.02910
ACTUAL RIG CONDITIONS										
P3, PSIA	171.36	171.24	171.81	171.38	172.27	171.85	170.78	173.02	171.01	171.90
T3, F	997.5	994.7	1035.2	1041.2	938.2	936.6	991.4	991.5	1035.6	1034.1
W36, PPS	40.33	42.08	40.53	40.44	42.38	43.03	40.85	41.64	40.56	40.68
WFE, PPH	4123.	4112.	4202.	4215.	4038.	4041.	4136.	4147.	4235.	4241.
FAR4	0.02861	0.02736	0.02902	0.02916	0.02673	0.02634	0.02853	0.02807	0.02945	0.02938
HUM, GR/LB	52.7	55.6	53.8	49.9	70.3	67.4	103.2	103.2	107.9	102.6
EMISSION DATA, MEASURED										
CO, PPM	121.8	111.5	103.7	89.2	102.1	52.4	123.9	59.5	101.7	96.6
CO2, PCT	6.006	5.649	6.302	6.097	5.692	5.600	5.804	5.956	6.046	6.302
HC, PPM	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
NOX, PPM	296.8	270.7	312.0	345.8	223.0	246.2	234.7	257.4	286.5	306.1
EICO	4.06	3.95	3.30	2.93	3.59	1.88	4.28	2.00	3.37	3.08
EIHC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	16.27	15.77	16.30	18.68	12.90	14.49	13.31	14.24	15.61	16.00
SMOKE	5.3	3.0	3.5	6.3	3.7	1.7	3.5	4.1	4.1	8.3
FARGAS	0.02985	0.02802	0.03135	0.03029	0.02823	0.02774	0.02881	0.02956	0.03004	0.03134
EFF, PCT	99.90	99.90	99.91	99.92	99.91	99.95	99.89	99.94	99.91	99.92
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	4.06	3.95	3.30	2.93	3.59	1.88	4.28	2.00	3.37	3.08
EIHC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOX	21.03	20.39	21.05	24.15	16.65	18.72	17.23	18.34	20.19	20.66
SMOKE	15.0	8.6	9.9	17.7	10.3	4.7	10.0	11.6	11.6	23.4
EFF, PCT	99.91	99.91	99.92	99.93	99.92	99.96	99.90	99.95	99.92	99.93

CFM56 COMBUSTOR RIG DATA

CASE	201	202	203	204	205	206	207	208	209	210
RDG	170	205	213	220	214	227	236	241	156	192
POINT	5A13	5B13	5A15	5B15	5A16	5B16	5A17	5B17	5A19	5B19
DATE	12/13/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/14/76	12/13/76	12/13/76
SIMULATED ENGINE CONDITIONS										
POWER	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
FN, LBS	21554.	21554.	23737.	23737.	23737.	23737.	23737.	23737.	19106.	19106.
FNK, LBS	22000.	22000.	22000.	22000.	22000.	22000.	22001.	22001.	22000.	22000.
TAMB, F	85.0	85.0	19.0	19.0	59.0	59.0	105.0	105.0	19.0	19.0
PAMB, PSIA	14.398	14.398	15.856	15.856	15.856	15.856	15.856	15.856	12.763	12.763
H:M, GR/LB	175.0	175.0	14.0	14.0	52.5	52.5	14.0	14.0	14.0	14.0
P3, PSIA	342.72	342.72	377.89	377.89	378.20	378.20	377.93	377.93	304.06	304.06
T3, F	994.9	994.9	847.9	847.9	941.0	941.0	1048.8	1048.8	847.8	847.8
W36, PPS	82.08	82.08	95.88	95.88	92.86	92.86	89.80	89.80	77.09	77.09
WFE, PPH	8269.	8269.	8430.	8430.	8785.	8785.	9153.	9153.	6805.	6805.
FAR4	0.02870	0.02870	0.02450	0.02450	0.02650	0.02650	0.02840	0.02840	0.02460	0.02460
ACTUAL RIG CONDITIONS										
P3, PSIA	171.36	170.88	188.70	190.45	189.11	188.74	191.07	188.14	152.73	153.04
T3, F	991.5	988.3	840.5	848.6	934.3	943.5	1047.0	1042.2	846.5	847.7
W36, PPS	40.76	40.89	48.89	48.53	46.00	45.31	45.46	45.60	39.52	38.51
WFE, PPH	4164.	4206.	4250.	4230.	4445.	4425.	4619.	4635.	3440.	3439.
FAR4	0.02909	0.02929	0.02419	0.02429	0.02704	0.02734	0.02829	0.02829	0.02422	0.02485
H:M, GR/LB	177.1	175.8	12.9	22.9	53.2	53.9	15.4	14.4	11.7	11.5
EMISSION DATA, MEASURED										
CO, PPM	124.9	145.6	138.6	38.8	136.0	49.1	73.0	70.4	78.3	107.4
CO2, PCT	5.765	6.016	5.116	5.297	5.635	5.757	5.867	6.087	5.240	5.196
HC, PPM	0.	0.	0.	0.	0.	0.	0.	0.	0.2	0.
NOX, PPM	210.4	230.6	196.8	211.4	240.9	222.2	390.2	388.0	192.4	189.0
EICO	4.34	4.85	5.43	1.47	4.83	1.71	2.50	2.32	2.99	4.14
EIHC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOx	12.01	12.61	12.66	13.15	14.07	12.72	21.91	21.00	12.09	11.97
SMOKE	4.9	4.2	2.5	3.1	4.4	4.1	4.3	5.3	4.0	2.4
FARGAS	0.02862	0.02991	0.02533	0.02619	0.02796	0.02853	0.02911	0.03023	0.02593	0.02571
EFF, PCT	99.89	99.88	99.86	99.96	99.88	99.95	99.93	99.94	99.92	99.89
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.										
EICO	4.34	4.85	5.43	1.47	4.83	1.71	2.50	2.32	2.99	4.14
EIHC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
EINOx	15.52	16.31	16.37	16.94	18.18	16.45	28.20	27.18	15.60	15.43
SMOKE	13.9	12.0	7.2	8.7	12.4	11.7	12.0	15.2	11.3	6.7
EFF, PCT	99.90	99.89	99.87	99.97	99.89	99.96	99.94	99.95	99.93	99.90

CFM56 COMBUSTOR RIG DATA

CASE	211	212	213	214
RDG	193	197	165	196
POINT	5A20	5B20	5A21	5B21
DATE	12/13/76	12/14/76	12/13/76	12/14/76
SIMULATED ENGINE CONDITIONS				
POWER	T/O	T/O	T/O	T/O
FN, LBS	19106.	19106.	19106.	19106.
FNK, LBS	22000.	22000.	22000.	22000.
TAMB, F	59.0	59.0	105.0	105.0
PAMB, PSIA	12.763	12.763	12.763	12.763
HUM, GR/LB	52.5	52.5	14.0	14.0
P3, PSIA	304.21	304.21	303.99	303.99
T3, F	940.9	940.9	1048.8	1048.8
W36, PPS	74.60	74.60	72.13	72.13
WFE, PPH	7098.	7098.	7399.	7399.
FAR4	0.02660	0.02660	0.02850	0.02850
ACTUAL RIG CONDITIONS				
P3, PSIA	153.04	152.61	152.51	153.28
T3, F	942.3	930.4	1049.0	1041.0
W36, PPS	37.52	36.86	35.85	36.41
WFE, PPH	3579.	3590.	3742.	3726.
FAR4	0.02670	0.02726	0.02904	0.02848
HUM, GR/LB	52.6	53.6	11.3	12.2
EMISSION DATA, MEASURED				
CO, PPM	84.6	126.2	107.1	150.6
CO2, PCT	5.517	5.823	6.199	6.001
HC, PPM	0.	0.	0.2	0.
NOX, PPM	224.2	223.7	375.4	341.8
EICO	3.08	4.34	3.46	5.03
EIHC	0.	0.	0.	0.
EINOX	13.39	12.65	19.94	18.74
SMOKE	3.8	4.6	3.2	3.7
FARGAS	0.02733	0.02891	0.03082	0.02983
EFF, PCT	99.92	99.89	99.91	99.87
EMISSION DATA, CORRECTED TO SIM. ENGINE COND.				
EICO	3.08	4.34	3.46	5.03
EIHC	0.	0.	0.	0.
EINOX	17.27	16.33	25.74	24.14
SMOKE	10.5	12.9	9.0	10.3
EFF, PCT	99.93	99.90	99.92	99.88

APPENDIX B

ENGINE TEST DATA

This appendix contains complete tabulations of the CFM56 engine test data. The nomenclature is defined below. Note that "ambient" temperature and pressure are measured at the engine fan inlet, rather than outside the test cell.

Engine data is tabulated only once for each test point. The engine data for each parameter is the average of the several data readings (ADH) taken at each test point, and the reading number corresponds to the first ADH reading.

NOMENCLATURE FOR ENGINE TEST DATA

CASE	Consecutively numbered on table
RDG	Test reading number (Automatic Data Handling System)
POINT	Test point number indicating power level (1, 2, 3, 4, 5) and replication (A, B, C, etc.)
DATE	Test date
POWER	Nominal engine power level; IDL (6%), 1.5 IDL (9%), APP (30%), C/O (85%), T/O (100%)
FNK, LB	Corrected thrust = Fn * 14.696/P2
TAMB, ° F	Fan inlet temperature
PAMB, PSIA	Fan inlet pressure
HUM, GR/LB	Ambient humidity
P3, PSIA	Compressor discharge pressure
T3, ° F	Compressor discharge temperature
WFE, PPH	Engine fuel flow
FAR57	Core engine exhaust fuel/air ratio
RAKE	Rake identification (A or B)
POSITION	Rake angular position, degrees
CO, PPM	CO concentration (wet)
CO2, PCT	CO_2 concentration (wet)

HC, PPM	Hydrocarbons (equivalent CH_4) concentration (wet)
NOX, PPM	NO_x concentration (wet)
EICO	CO emission index, lb of CO per 1000 lb of fuel
EIHC	HC emission index, lb of HC per 1000 lb of fuel
EINOX	NO_x emission index, lb of NO_x per 1000 lb of fuel
SMOKE	Smoke number
FARGAS	Fuel/air ratio calculated from sample composition
EFF, PCT	Combustion efficiency calculated from sample composition

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CFM56 ENGINE DATA

CASE	1	2	3	4	5	6	7	8	9	10
RDG	133		173		242					
POINT	1A		1B		1C					
DATE	10/28/77		11/ 3/77		11/10/77					
ENGINE DATA										
POWER	IDL		IDL		IDL					
FNK, LBS	1363.		1389.		1378.					
TAMB, F	55.7		70.0		43.7					
PAMB, PSIA	14.500		14.436		14.340					
HUM, GR/LB	47.0		72.6		19.0					
P3, PSIA	51.80		52.30		51.80					
T3, F	368.9		394.6		351.7					
WFE, PPH	863.		885.		860.					
FAR57	0.01103		0.01137		0.01086					
EMISSION DATA										
RAKE	A	B	A	B	A	A	A	A	A	A
POSITION	0.0	0.0	0.0	0.0	0.0	5.9	13.6	21.3	28.9	36.5
CO, PPM	188.6	231.5	206.9	234.2	178.6	214.7	255.5	303.3	329.0	326.1
CO2, PCT	1.410	1.760	1.450	1.690	1.200	1.390	1.710	2.040	2.240	2.220
HC, PPM	15.2	16.9	8.3	9.1	11.4	13.0	12.8	14.4	16.0	15.7
NOX, PPM	16.1	18.7	19.1	21.1	15.0	17.0	21.3	24.9	27.1	27.0
EICO	26.40	26.10	28.20	27.40	29.30	30.50	29.50	29.30	29.10	29.10
EIHC	1.20	1.10	0.60	0.60	1.10	1.10	0.80	0.80	0.80	0.80
EINOX	3.70	3.50	4.30	4.10	4.10	4.00	4.00	4.00	3.90	3.90
SMOKE	2.3	2.0	2.4	2.6	2.8	0.	0.	0.	0.	0.
FARGAS	0.00694	0.00866	0.00716	0.00833	0.00590	0.00687	0.00845	0.01010	0.01105	0.01097
EFF, PCT	99.28	99.30	99.29	99.31	99.22	99.20	99.24	99.25	99.25	99.25

CFM56 ENGINE DATA

CASE	11	12	13	14	15	16	17	18	19	20
RDG									275	
POINT									1D	
DATE									11/10/77	
ENGINE DATA										
POWER									IDL	
FNK, LBS									1384.	
TAMB, F									38.7	
PAMB, PSIA									14.390	
HUM, GR/LB									19.0	
P3, PSIA									51.60	
T3, F									343.8	
WFE, PPH									848.	
FAR57									0.01067	
EMISSION DATA										
RAKE	A	B	B	B	B	B	B	B	A	A
POSITION	44.1	0.0	5.9	13.6	21.3	28.9	36.5	44.1	0.0	44.1
CO, PPM	328.4	243.2	233.8	251.3	230.7	188.3	136.1	119.9	195.5	346.6
CO2, PCT	2.270	1.660	1.590	1.690	1.560	1.270	0.900	0.770	1.230	2.140
HC, PPM	13.8	11.2	10.4	11.5	11.8	9.9	9.0	8.0	12.7	16.4
NOX, PPM	27.2	19.7	19.1	20.4	19.2	15.9	11.6	9.7	15.7	26.5
EICO	28.70	29.00	29.00	29.40	29.30	29.30	30.00	30.90	31.30	32.00
EIHC	0.70	0.80	0.70	0.80	0.90	0.90	1.10	1.20	1.20	0.90
EINOX	3.90	3.90	3.90	3.90	4.00	4.10	4.20	4.10	4.10	4.00
SMOKE	2.4	2.8	0.	0.	0.	0.	0.	2.8	2.1	2.7
FARGAS	0.01120	0.00817	0.00785	0.00835	0.00768	0.00626	0.00441	0.00377	0.00608	0.01058
EFF, PCT	99.27	99.26	99.26	99.25	99.24	99.24	99.20	99.18	99.17	99.18

CFM56 ENGINE DATA

CASE	21	22	23	24	25	26	27	28	29	30
RDG			293				321			
POINT			1E				1F			
DATE			11/14/77				11/16/77			
ENGINE DATA										
POWER			IDL				IDL			
FNK, LBS			1370.				1369.			
TAMB, F			51.4				49.8			
PAMB, PSIA			14.470				14.300			
HUM, GR/LB			22.0				46.0			
P3, PSIA			51.90				51.10			
T3, F			363.3				363.1			
WFE, PPH			867.				851.			
FAR57			0.01098				0.01110			
EMISSION DATA										
RAKE	B	B	A	A	B	B	A	A	B	B
POSITION	0.0	44.1	0.0	44.1	0.0	44.1	0.0	44.1	0.0	44.1
CO, PPM	267.0	156.0	192.3	326.1	246.9	155.1	188.7	332.6	238.3	156.5
CO2, PCT	1.600	0.930	1.300	2.280	1.690	1.020	1.330	2.330	1.740	1.080
HC, PPM	14.9	10.4	14.4	15.1	11.5	12.6	13.5	13.5	13.0	11.3
NOX, PPM	20.3	12.5	17.0	28.3	21.6	13.9	14.5	21.5	17.5	11.1
EICO	32.90	33.10	29.30	28.20	28.90	29.90	28.10	28.20	27.10	28.70
EIHC	1.10	1.30	1.30	0.70	0.80	1.40	1.20	0.70	0.80	1.20
EINOX	4.10	4.40	4.20	4.00	4.10	4.40	3.60	3.00	3.30	3.30
SMOKE	2.2	2.1	2.8	2.7	2.6	2.7	1.6	1.6	1.6	1.8
FARGAS	0.00792	0.00457	0.00638	0.01129	0.00834	0.00503	0.00653	0.01154	0.00858	0.00529
EFF, PCT	99.14	99.12	99.21	99.28	99.26	99.18	99.24	99.28	99.29	99.23

CFM56 ENGINE DATA

CASE	31	32	33	34	35	36	37	38	39	40
RDG	135									
POINT	2A									
DATE	10/28/77									
ENGINE DATA										
POWER	1.5IDL									
FNK, LBS	2119.									
TAMB, F	54.7									
PAMB, PSIA	14.490									
HUM, GR/LB	48.0									
P3, PSIA	67.70									
T3, F	430.4									
WFE, PPH	1088.									
FAR57	0.01085									
EMISSION DATA										
RAKE	A	B	B	B	B	B	B	B	B	B
POSITION	0.0	0.0	3.2	8.5	13.6	18.7	23.8	28.9	34.0	39.1
CO, PPM	103.7	130.6	129.9	137.4	148.7	136.0	117.3	101.7	86.0	80.8
CO2, PCT	1.370	1.760	1.600	1.640	1.710	1.590	1.400	1.230	1.020	0.990
HC, PPM	10.4	10.2	9.8	11.0	11.6	11.6	11.3	13.0	10.7	10.1
NOX, PPM	18.5	22.6	22.0	22.1	23.2	22.1	19.9	17.4	15.0	14.5
EICO	15.10	14.80	16.20	16.70	17.30	17.00	16.60	16.50	16.80	16.20
EIHC	0.90	0.70	0.70	0.80	0.80	0.80	0.90	1.20	1.20	1.20
EINOX	4.40	4.20	4.50	4.40	4.40	4.50	4.60	4.60	4.80	4.80
SMOKE	2.3	2.1	0.	0.	0.	0.	0.	0.	0.	0.
FARGAS	0.00669	0.00861	0.00783	0.00803	0.00836	0.00780	0.00687	0.00600	0.00497	0.00485
EFF, PCT	99.57	99.60	99.56	99.54	99.53	99.53	99.53	99.51	99.50	99.52

CFM56 ENGINE DATA

CASE	41	42	43	44	45	46	47	48	49	50
RDG		175		245						
POINT		2B		2C						
DATE		11/ 3/77		11/10/77						
ENGINE DATA										
POWER		1.5IDL		1.5IDL						
FNK, LBS		2140.		2153.						
TAMB, F		69.3		42.9						
PAMB, PSIA		14.420		14.340						
HUM, GR/LB		72.0		18.0						
P3, PSIA		67.90		67.60						
T3, F		456.8		418.0						
WFE, PPH		1114.		1099.						
FAR57		0.01132		0.01091						
EMISSION DATA										
RAKE	B	A	B	A	A	A	A	A	A	A
POSITION	44.1	0.0	0.0	0.0	5.9	13.6	21.3	28.9	36.5	44.1
CO, PPM	86.4	128.7	141.5	104.8	118.9	142.4	167.1	180.7	181.1	179.6
CO2, PCT	1.040	1.410	1.690	1.210	1.350	1.670	1.990	2.200	2.220	2.240
HC, PPM	10.7	5.3	4.8	4.0	4.2	4.0	3.7	3.4	3.4	4.3
NOX, PPM	15.2	21.9	25.1	17.9	20.3	24.8	29.4	32.5	32.5	32.8
EICO	16.60	18.20	16.70	17.30	17.50	17.00	16.70	16.30	16.30	15.90
EIHC	1.20	0.40	0.30	0.40	0.40	0.30	0.20	0.20	0.20	0.20
EINOX	4.80	5.10	4.90	4.80	4.90	4.80	4.80	4.80	4.80	4.80
SMOKE	0.	2.7	2.2	2.1	0.	0.	0.	0.	0.	1.5
FARGAS	0.00506	0.00688	0.00829	0.00589	0.00589	0.00819	0.00977	0.01082	0.01090	0.01101
EFF, PCT	99.51	99.54	99.58	99.56	99.56	99.58	99.59	99.60	99.61	99.61

CFM56 ENGINE DATA

CASE	51	52	53	54	55	56	57	58	59	60
RDG								283		
POINT								2D		
DATE								11/10/77		
ENGINE DATA										
POWER								1.5IDL		
FNK, LBS								2254.		
TAMB, F								39.1		
PAMB, PSIA								14.390		
HUM, GR/LB								18.0		
P3, PSIA								70.40		
T3, F								421.3		
WFE, PPH								1101.		
FAR57								0.01051		
EMISSION DATA										
RAKE	B	B	B	B	B	B	B	A	A	B
POSITION	0.0	5.9	13.6	21.3	28.9	36.5	44.1	0.0	44.1	0.0
CO, PPM	132.4	132.5	142.3	128.3	106.5	87.9	83.5	98.4	146.7	129.5
CO2, PCT	1.660	1.620	1.710	1.840	1.270	0.990	0.940	1.150	2.160	1.580
HC, PPM	2.7	2.6	2.9	3.4	3.8	3.7	3.8	5.6	3.8	3.9
NOX, PPM	24.4	23.9	25.1	23.1	19.1	14.6	13.9	20.3	34.5	26.1
EICO	15.90	16.30	16.50	13.90	16.80	17.70	17.60	17.10	13.50	16.30
EIHC	0.20	0.20	0.20	0.20	0.30	0.40	0.50	0.60	0.20	0.30
EINOX	4.80	4.80	4.80	4.10	4.90	4.80	4.80	5.80	5.20	5.40
SMOKE	1.3	0.	0.	0.	0.	0.	1.4	1.8	2.1	2.0
FARGAS	0.00811	0.00794	0.00839	0.00902	0.00619	0.00481	0.00460	0.00560	0.01059	0.00774
EFF, PCT	99.61	99.60	99.60	99.66	99.58	99.55	99.55	99.55	99.67	99.60

CFM56 ENGINE DATA

CASE	61	62	63	64	65	66	67	68	69	70
RDG		295				323				137
POINT		2E				2F				3A
DATE		11/14/77				11/16/77				10/28/77
ENGINE DATA										
POWER		1.5IDL				1.5IDL				APP
FNK, LBS		2245.				2155.				6672.
TAMB, F		49.7				49.2				55.3
PAMB, PSIA		14.430				14.300				14.470
HUM, GR/LB		23.0				47.0				49.0
P3, PSIA		70.00				67.20				140.50
T3, F		436.4				429.5				615.5
WFE, PPH		1143.				1110.				2465.
FAR57		0.01107				0.01124				0.01300
EMISSION DATA										
RAKE	B	A	A	B	B	A	A	B	B	A
POSITION	44.1	0.0	44.1	0.0	44.1	0.0	44.0	0.0	44.1	0.0
CO, PPM	76.8	100.6	168.0	132.3	76.8	109.7	183.4	143.6	89.6	27.9
CO2, PCT	0.890	1.220	2.280	1.710	0.970	1.300	2.340	1.770	1.040	1.490
HC, PPM	4.3	8.1	5.5	5.7	6.3	5.2	3.9	3.6	4.7	6.7
NOX, PPM	15.9	19.5	34.8	26.6	15.5	18.2	32.5	24.8	15.6	37.6
EICO	17.10	16.40	14.70	15.40	15.70	16.90	15.60	16.20	17.20	3.70
EIHC	0.50	0.80	0.30	0.40	0.70	0.50	0.20	0.20	0.50	0.50
EINOX	5.80	5.20	5.00	5.10	5.20	4.60	4.50	4.60	4.90	8.30
SMOKE	0.4	2.3	2.6	2.6	2.3	1.1	1.5	1.7	1.4	2.0
FARGAS	0.00435	0.00598	0.01117	0.00835	0.00475	0.00633	0.01149	0.00867	0.00507	0.00726
EFF, PCT	99.55	99.55	99.63	99.61	99.57	99.57	99.62	99.60	99.55	99.87

CFM56 ENGINE DATA

CASE	71	72	73	74	75	76	77	78	79	80
RDG		177		250						
POINT		38		3C						
DATE		11/ 3/77		11/10/77						
ENGINE DATA										
POWER		APP		APP						
FNK, LBS		6752.		6733.						
TAMB, F		69.3		41.0						
PAMB, PSIA		14.380		14.350						
HUM, GR/LB		72.0		19.0						
P3, PSIA		140.20		139.40						
T3, F		645.1		587.9						
WFE, PPH		2528.		2477.						
FAR57		0.01364		0.01303						
EMISSION DATA										
RAKE	B	A	B	A	A	A	A	A	A	A
POSITION	0.0	0.0	0.0	0.0	5.9	13.6	21.3	28.9	36.5	44.1
CO, PPM	38.5	47.2	52.6	42.6	43.9	47.8	54.1	60.1	61.2	60.2
CO2, PCT	2.220	1.700	2.230	1.540	1.530	1.740	2.070	2.360	2.500	2.540
HC, PPM	6.7	2.9	2.2	1.8	2.6	2.6	2.2	2.1	2.1	1.9
NOX, PPM	56.1	44.5	56.8	38.4	39.9	46.5	55.9	63.2	65.7	66.4
EICO	3.50	5.60	4.70	5.50	5.70	5.50	5.20	5.10	4.90	4.70
EIHC	0.36	0.20	0.16	0.10	0.20	0.20	0.10	0.10	0.10	0.10
EINOX	8.30	8.60	8.40	8.20	8.60	8.80	8.90	8.80	8.60	8.60
SMOKE	1.3	3.3	2.8	2.8	0.	0.	0.	0.	0.	2.4
FARGAS	0.01081	0.00827	0.01088	0.00748	0.00745	0.00849	0.01012	0.01153	0.01224	0.01243
EFF, PCT	99.89	99.85	99.88	99.86	99.85	99.86	99.87	99.87	99.88	99.88

CFM56 ENGINE DATA

CASE	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
RDG								277		
POINT								30		
DATE								11/10/77		
ENGINE DATA										
POWER								APP		
FNK, LBS								6987.		
TAMB, F								38.8		
PAMB, PSIA								14.360		
HUM, GR/LB								19.0		
P3, PSIA								142.60		
T3, F								592.0		
WFE, PPH								2509.		
FAR57								0.01288		
EMISSION DATA										
RAKE	B	B	B	B	B	B	B	A	A	B
POSITION	0.0	5.9	13.6	21.3	28.9	36.5	44.1	0.0	44.1	0.0
CO, PPM	50.6	50.3	50.8	46.3	40.8	37.1	33.8	39.0	55.5	45.6
CO2, PCT	2.100	2.010	1.980	1.840	1.580	1.290	1.020	1.550	2.670	2.080
HC, PPM	1.8	2.1	2.1	2.2	2.4	2.6	2.9	2.4	1.0	1.9
NOX, PPM	54.4	52.3	52.0	48.2	41.3	34.2	27.2	41.8	69.2	56.0
EICO	4.80	5.00	5.10	5.00	5.20	5.70	6.60	5.00	4.20	4.40
EIHC	0.10	0.10	0.10	0.10	0.20	0.20	0.30	0.20	0.00	0.10
EINOX	8.50	8.50	8.60	8.60	8.60	8.70	8.80	8.90	8.50	8.90
SMOKE	2.2	0.	0.	0.	0.	0.	2.0	1.6	2.8	2.6
FARGAS	0.01023	0.00982	0.00967	0.00898	0.00769	0.00628	0.00494	0.00753	0.01306	0.01014
EFF, PCT	99.88	99.87	99.87	99.87	99.86	99.85	99.82	99.87	99.90	99.89

CFM56 ENGINE DATA

CASE	91	92	93	94	95	96	97	98	99	100
RDG		302				325				139
POINT		3E				3F				4A
DATE		11/14/77				11/16/77				10/28/77
ENGINE DATA										
POWER		APP				APP				CLI
FNK, LBS		6842.				6960.				18985.
TAMB, F		50.9				49.2				55.6
PAMB, PSIA		14.400				14.270				14.400
HUM, GR/LB		23.5				47.0				50.0
P3, PSIA		141.60				141.30				296.30
T3, F		612.8				611.5				880.9
WFE, PPH		2508.				2538.				6795.
FAR57		0.01309				0.01337				0.01953
EMISSION DATA										
RAKE	B	A	A	B	B	A	A	B	B	A
POSITION	44.1	0.0	44.1	0.0	44.1	0.0	44.1	0.0	44.1	0.0
CO, PPM	25.4	44.6	60.8	52.2	34.3	45.4	60.4	52.1	35.5	12.9
CO2, PCT	0.890	1.680	2.740	2.240	1.070	1.710	2.710	2.260	1.080	3.040
HC, PPM	2.2	2.4	1.8	1.6	2.6	2.6	1.3	2.0	2.4	2.5
NOX, PPM	24.9	41.1	68.1	56.2	27.0	39.6	64.0	53.1	26.4	133.3
EICO	5.70	5.30	4.40	4.70	6.40	5.30	4.50	4.60	6.60	0.90
EIHC	0.30	0.20	0.10	0.10	0.30	0.20	0.10	0.10	0.30	0.10
EINOX	9.20	8.10	8.20	8.30	8.30	7.60	7.80	7.70	8.00	14.40
SMOKE	1.7	2.5	2.5	1.8	1.4	1.9	1.2	1.7	1.0	4.9
FARGAS	0.00430	0.00817	0.01341	0.01092	0.00519	0.00834	0.01325	0.01102	0.00523	0.01488
EFF, PCT	99.84	99.86	99.89	99.88	99.83	99.86	99.89	99.88	99.82	99.97

CFM56 ENGINE DATA

CASE	101	102	103	104	105	106	107	108	109	110
RDG		179		255						
POINT		48		4C						
DATE		11/ 3/77		11/10/77						
ENGINE DATA										
POWER		CLI		CLI						
FNK, LBS		18917.		19203.						
TAMB, F		69.1		39.7						
PAMB, PSIA		14.270		14.280						
HUM, GR/LB		72.0		19.0						
P3, PSIA		293.90		294.90						
T3, F		910.0		847.0						
WFE, PPH		6875.		6686.						
FAR57		0.02024		0.01899						
EMISSION DATA										
RAKE	B	A	B	A	A	A	A	A	A	A
POSITION	0.0	0.0	0.0	0.0	5.9	13.6	21.3	28.9	36.5	44.1
CO, PPM	13.7	29.2	28.5	20.8	21.1	20.3	20.3	20.1	20.6	19.3
CO2, PCT	3.740	3.230	3.830	3.310	3.140	3.130	3.150	3.220	3.650	3.940
HC, PPM	1.5	1.8	1.0	3.5	4.2	5.6	5.8	5.0	3.0	1.4
NOX, PPM	163.5	139.5	166.1	140.8	134.7	135.0	135.6	137.7	153.7	164.2
EICO	0.70	1.80	1.50	1.30	1.40	1.30	1.30	1.30	1.10	1.00
EIHC	0.00	0.10	0.00	0.10	0.20	0.20	0.20	0.20	0.10	0.00
EINOX	14.40	14.20	14.30	14.00	14.10	14.20	14.20	14.10	13.90	13.70
SMOKE	2.4	7.5	5.7	9.3	0.	0.	0.	0.	0.	4.8
FARGAS	0.01835	0.01583	0.01880	0.01619	0.01535	0.01531	0.01539	0.01575	0.01790	0.01935
EFF, PCT	99.98	99.95	99.96	99.96	99.96	99.95	99.95	99.96	99.97	99.97

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CFM56 ENGINE DATA

CASE	111	112	113	114	115	116	117	118	119	120
RDG								279		
POINT								4D		
DATE								11/10/77		
ENGINE DATA										
POWER								CLI		
FNK, LBS								19436.		
TAMB, F								39.0		
PAMB, PSIA								14.290		
HUM, GR/LB								19.0		
P3, PSIA								296.40		
T3, F								848.6		
WFE, PPH								6773.		
FARST								0.01918		
EMISSION DATA										
RAKE	B	B	B	B	B	B	B	A	A	B
POSITION	0.0	5.9	13.6	21.3	28.9	36.5	44.1	0.0	44.1	0.0
CO, PPM	19.0	19.5	19.6	18.6	16.8	18.4	16.8	20.6	18.6	17.3
CO2, PCT	3.640	3.560	3.510	3.120	2.780	2.580	2.310	3.300	3.770	3.570
HC, PPM	2.2	2.4	2.6	2.2	2.4	2.1	1.4	0.9	1.9	0.9
NOX, PPM	155.0	153.4	149.4	135.0	121.2	112.0	99.5	150.5	174.4	165.5
EICO	1.00	1.10	1.10	1.20	1.20	1.40	1.50	1.30	1.00	1.00
EIHC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.10	0.00
EINOX	14.10	14.20	14.00	14.30	14.40	14.30	14.20	15.00	15.30	15.30
SMOKE	3.1	0.	0.	0.	0.	0.	5.3	10.3	4.5	3.5
FARGAS	0.01785	0.01743	0.01720	0.01526	0.01360	0.01257	0.01123	0.01616	0.01848	0.01748
EFF, PCT	99.97	99.97	99.97	99.96	99.96	99.96	99.96	99.97	99.97	99.97

CFM56 ENGINE DATA

CASE	121	122	123	124	125	126	127	128	129	130
RDG		313				327				
POINT		4E				4F				
DATE		11/15/77				11/16/77				
ENGINE DATA										
POWER		CLI				CLI				
FNK, LBS		19065.				19292.				
TAMB, F		60.0				49.2				
PAMB, PSIA		14.250				14.190				
HUM, GR/LB		39.0				46.0				
P3, PSIA		292.00				293.90				
T3, F		892.0				869.8				
WFE, PPH		6821.				6806.				
FAR57		0.02000				0.01969				
EMISSION DATA										
RAKE	B	A	A	B	B	A	A	A	A	A
POSITION	44.1	0.0	44.1	0.0	44.1	0.0	5.9	13.6	21.3	28.9
CO, PPM	14.3	26.6	24.1	23.4	21.6	21.8	21.2	20.4	20.8	19.9
CO2, PCT	2.090	3.360	4.070	3.740	2.220	3.340	3.230	3.170	3.180	3.230
HC, PPM	1.5	3.5	2.4	2.6	2.6	2.8	3.9	6.4	7.2	6.4
NOX, PPM	100.4	153.8	187.6	172.4	105.5	146.8	141.6	142.5	141.3	142.2
EICO	1.40	1.60	1.20	1.30	2.00	1.30	1.30	1.30	1.30	1.20
EIHC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.30	0.20
EINOX	15.90	15.10	15.20	15.20	15.70	14.50	14.50	14.80	14.60	14.50
SMOKE	6.3	11.5	6.4	3.7	7.0	11.5	13.9	15.5	15.2	14.1
FARGAS	0.01016	0.01645	0.01998	0.01833	0.01080	0.01635	0.01579	0.01549	0.01558	0.01579
EFF, PCT	99.96	99.95	99.97	99.96	99.94	99.96	99.96	99.95	99.95	99.95

CFM56 ENGINE DATA

CASE	131	132	133	134	135	136	137	138	139	140
RDG										141
POINT										5A
DATE										10/28/77
ENGINE DATA										
POWER										T/O
FNK, LBS										22250.
TAMB, F										55.4
PAMB, PSIA										14.390
HUM, GR/LB										50.0
P3, PSIA										336.70
T3, F										933.2
WFE, PPH										8092.
FAR57										0.02097
EMISSION DATA										
RAKE	A	A	B	B	B	B	B	B	B	A
POSITION	36.5	44.1	0.0	5.9	13.6	21.3	28.9	36.5	44.1	0.0
CO, PPM	19.6	19.5	19.1	19.2	18.9	17.9	17.3	17.3	17.3	14.9
CO2, PCT	3.610	3.900	3.650	3.600	3.540	3.170	2.820	2.580	2.350	3.490
HC, PPM	3.3	1.6	1.5	1.8	1.8	2.0	1.6	1.6	3.1	2.0
NOX, PPM	156.3	168.5	161.4	159.3	156.3	139.5	126.0	115.3	104.3	177.7
EICO	1.10	1.00	1.10	1.10	1.10	1.10	1.20	1.30	1.50	0.90
EIHC	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.20	0.10
EINOX	14.30	14.20	14.60	14.60	14.60	14.50	14.80	14.70	14.60	16.80
SMOKE	6.0	6.5	4.4	3.7	5.3	5.6	3.2	4.8	9.0	8.6
FARGAS	0.01768	0.01916	0.01791	0.01764	0.01732	0.01549	0.01375	0.01260	0.01145	0.01711
EFF, PCT	99.97	99.97	99.97	99.97	99.97	99.97	99.97	99.96	99.95	99.97

CFM56 ENGINE DATA

CASE	141	142	143	144	145	146	147	148	149	150
RDG		181		258						
POINT		5B		5C						
DATE		11/ 3/77		11/10/77						
ENGINE DATA										
POWER		T/O		T/O						
FNK, LBS		22274.		22579.						
TAMB, F		69.0		39.9						
PAMB, PSIA		14.290		14.270						
HUM, GR/LB		72.0		19.0						
P3, PSIA		335.70		336.00						
T3, F		968.1		899.6						
WFE, PPH		8232.		7969.						
FAR57		0.02175		0.02034						
EMISSION DATA										
RAKE	B	A	B	A	A	A	A	A	A	A
POSITION	0.0	0.0	0.0	0.0	5.9	13.6	21.3	28.9	36.5	44.1
CO, PPM	14.3	27.5	26.6	23.0	22.0	20.8	20.5	19.7	20.4	18.9
CO2, PCT	4.080	3.700	4.230	3.720	3.590	3.540	3.460	3.460	3.780	4.130
HC, PPM	1.4	0.6	0.0	3.2	3.0	6.4	7.5	4.8	4.0	2.4
NOX, PPM	207.2	188.0	217.0	187.9	182.4	181.8	177.4	178.4	193.8	210.9
EICO	0.70	1.50	1.30	1.20	1.20	1.20	1.20	1.10	1.10	0.90
EIHC	0.00	0.00	0.00	0.10	0.10	0.20	0.20	0.20	0.10	0.10
EINOX	16.70	16.80	16.90	16.70	16.70	16.90	16.90	17.00	16.90	16.80
SMOKE	3.9	9.6	6.8	11.4	0.	0.	0.	0.	0.	7.2
FARGAS	0.02005	0.01815	0.02082	0.01824	0.01762	0.01734	0.01697	0.01697	0.01852	0.02030
EFF, PCT	99.98	99.96	99.97	99.96	99.96	99.95	99.95	99.96	99.96	99.97

CFM56 ENGINE DATA

CASE	151	152	153	154	155	156	157	158	159	160
RDG								281		
POINT								50		
DATE								11/10/77		
ENGINE DATA										
POWER								T/O		
FNK, LBS								22691.		
TAMB, F								38.9		
PAMB, PSIA								14.280		
HUM, GR/LB								18.0		
P3, PSIA								336.10		
T3, F								898.9		
WFE, PPH								8007.		
FAR57								0.02045		
EMISSION DATA										
RAKE	B	B	B	B	B	B	B	A	A	B
POSITION	0.0	5.9	13.6	21.3	28.9	36.5	44.1	0.0	44.1	0.0
CO, PPM	19.6	19.7	19.4	18.8	17.1	18.0	17.2	21.3	19.2	18.0
CO2, PCT	3.980	3.930	3.830	3.470	3.050	2.780	2.520	3.630	4.080	3.870
HC, PPM	1.8	2.9	2.9	2.1	2.2	2.1	2.4	3.2	2.0	2.4
NOX, PPM	201.6	203.4	195.4	179.0	158.6	148.2	134.7	197.6	220.0	212.6
EICO	1.00	1.00	1.00	1.10	1.10	1.30	1.40	1.20	0.90	0.90
EIHC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
EINOX	16.70	17.10	16.80	17.00	17.20	17.60	17.60	18.00	17.80	18.10
SMOKE	5.6	0.	0.	0.	0.	0.	7.2	12.1	7.8	5.5
FARGAS	0.01955	0.01930	0.01881	0.01701	0.01491	0.01356	0.01229	0.01779	0.02003	0.01898
EFF, PCT	99.97	99.97	99.97	99.97	99.97	99.96	99.96	99.96	99.97	99.97

CFM56 ENGINE DATA

CASE	161	162	163	164	165	166	167	168	169
RDG		315				329			
POINT		5E				5F			
DATE		11/15/77				11/16/77			
ENGINE DATA									
POWER		T/O				T/O			
FNK, LBS		22699.				22521.			
TAMB, F		60.0				49.0			
PAMB, PSIA		14.230				14.170			
HUM, GR/LB		39.0				47.0			
P3, PSIA		335.60				333.00			
T3, F		948.6				920.3			
WFE, PPH		8249.				8070.			
FAR57		0.02159				0.02110			
EMISSION DATA									
RAKE	B	A	A	B	B	A	A	B	B
POSITION	44.1	0.0	44.1	0.0	44.1	0.0	44.1	0.0	44.1
CO, PPM	16.2	26.6	22.8	22.7	19.9	13.2	14.1	10.3	11.5
CO2, PCT	2.360	3.870	4.320	4.130	2.680	3.740	4.140	3.950	2.600
HC, PPM	2.0	4.2	3.5	2.9	2.9	2.0	2.0	1.0	1.3
NOX, PPM	136.2	187.0	206.8	199.2	138.5	193.8	214.5	206.6	138.6
EICO	1.40	1.40	1.10	1.10	1.50	0.70	0.70	0.50	0.90
EIHC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.10
EINOX	19.00	15.90	15.80	15.90	17.00	17.10	17.10	17.20	17.60
SMOKE	9.0	14.9	9.0	12.0	10.0	15.9	8.3	7.9	8.9
FARGAS	0.01151	0.01900	0.02123	0.02027	0.01309	0.01832	0.02036	0.01939	0.01267
EFF, PCT	99.96	99.96	99.97	99.97	99.95	99.98	99.98	99.99	99.97

APPENDIX C

EFFECT OF EXHAUST FLOW DISTURBANCE ON ENGINE FUEL-AIR DISTRIBUTION

During the CFM56 engine tests, sample fuel/air ratios significantly lower than the core engine fuel/air ratio were measured at certain rake positions. In order to investigate this effect, the sampling rake assembly was rotated over a 45° span, and samples were obtained with Rakes A and B at 7.5° increments. Resulting values of sample fuel/air ratio, normalized by the corresponding calculated core fuel/air ratio, are shown as a function of rake, angular position, and power level in Figure 33. In this figure, angular position (θ) is defined as the angle of the rake arm which is in the first quadrant. Recall that each rake has four arms spaced at 90° intervals. With both Rakes A and B, the highest sample fuel/air ratios were measured at an angular position of 45°. Sample fuel/air ratios tended to decrease as the rakes were rotated to the 0° and 90° positions.

This behavior is explained by examination of detailed exhaust-plane pressure and temperature profiles obtained prior to emissions testing. Climb power pressure and temperature profiles at radial positions corresponding to Rake B sampling orifices are presented in Figures 34 and 35. These profiles show a region of low temperature and high pressure near the 12 o'clock (0°) position. This is apparently the result of a wake in the fan stream behind the engine support pylon. In this wake region the fan air penetrates toward the engine centerline. As the rakes approach the 0° or 90° position, the top rake arm enters this wake region, and the sample is diluted by flow through this arm.

An elementary analysis was conducted to quantify the effects of the pylon wake on sample fuel/air ratio measurements. This analysis used data from the exit-temperature/pressure survey to predict sample fuel/air ratio as a function of rake position and rake internal pressure.

It was assumed that sample flow through each orifice, W_s, was composed of a component of core flow, W_c, at core temperature, T_c, having core carbon atom content, $[C]_c$, and a component of fan flow, W_f, at fan temperature, T_f, having a fan carbon atom content, $[C]_f \approx 0$. In the above, carbon atom content includes carbon in CO_2, CO, and HC. Adiabatic mixing of these components was assumed.

With these assumptions, it was possible to define the relationship between sample temperature, T_s, and sample fuel/air ratio, f_s, as follows:

Sample Continuity

$$W_s = W_f + W_c \qquad (5)$$

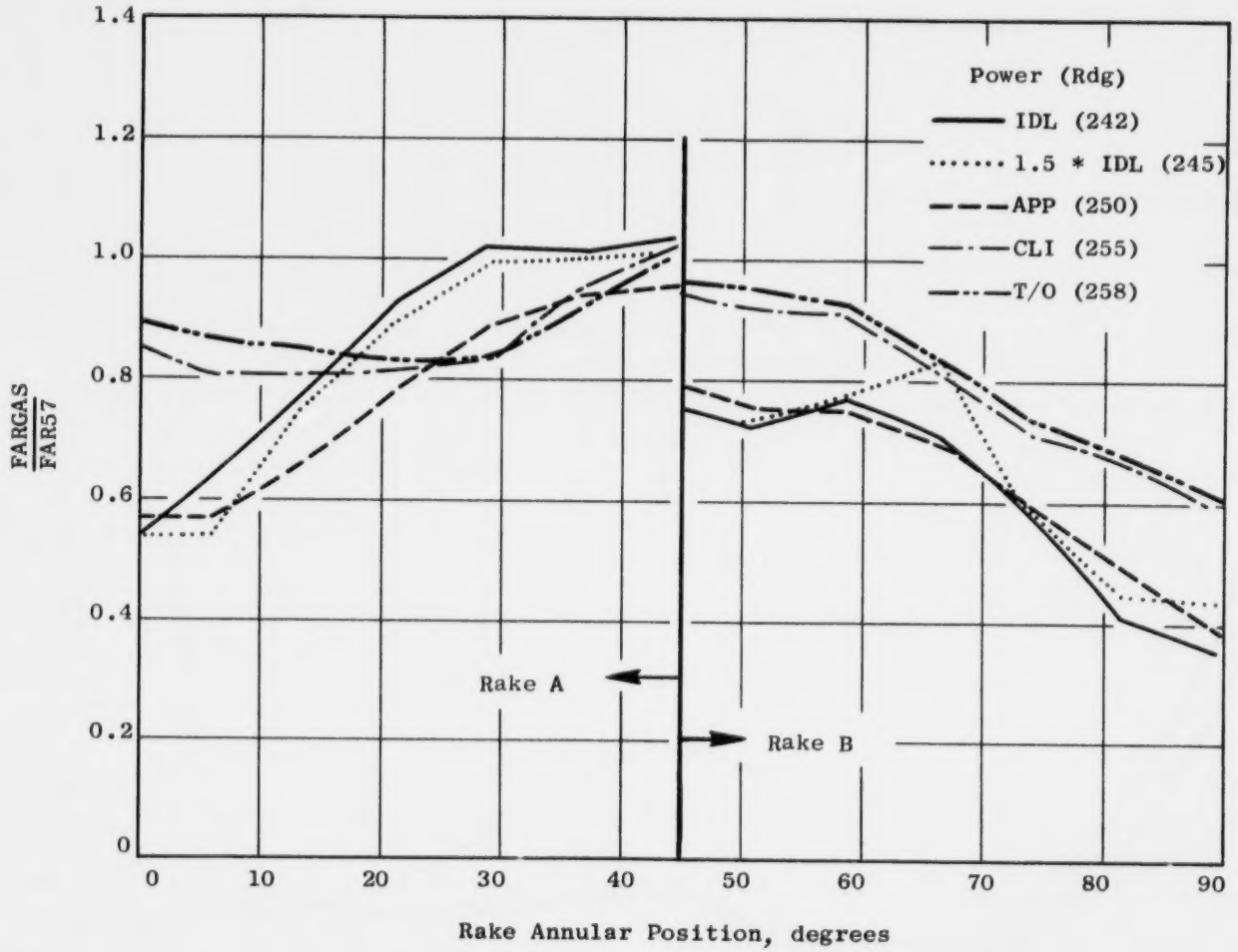

Figure 33. Fuel/Air Ratio Profiles for CFM56 Engine Test.

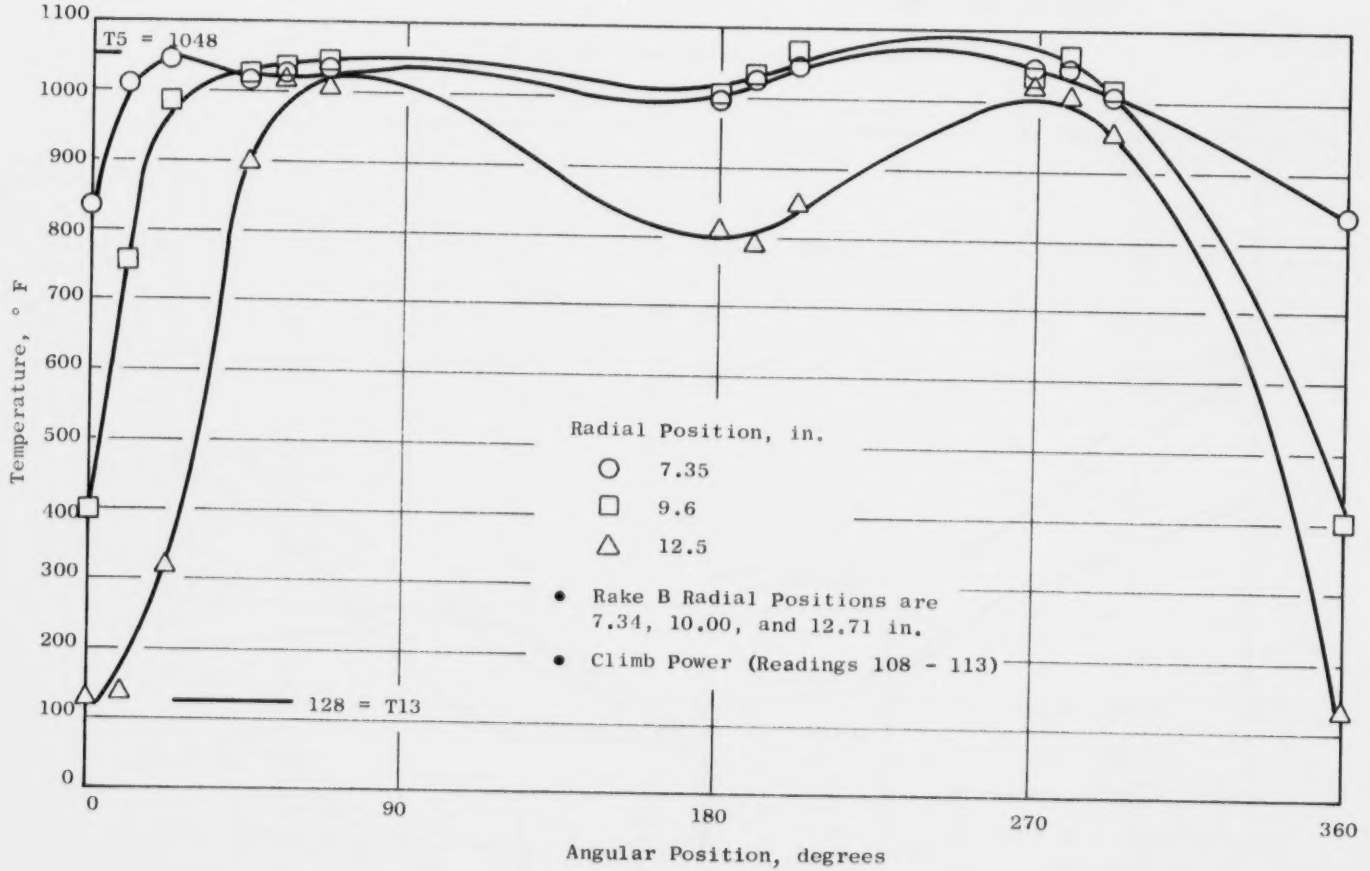

Figure 34. Climb Power Engine Exit Temperature Profiles.

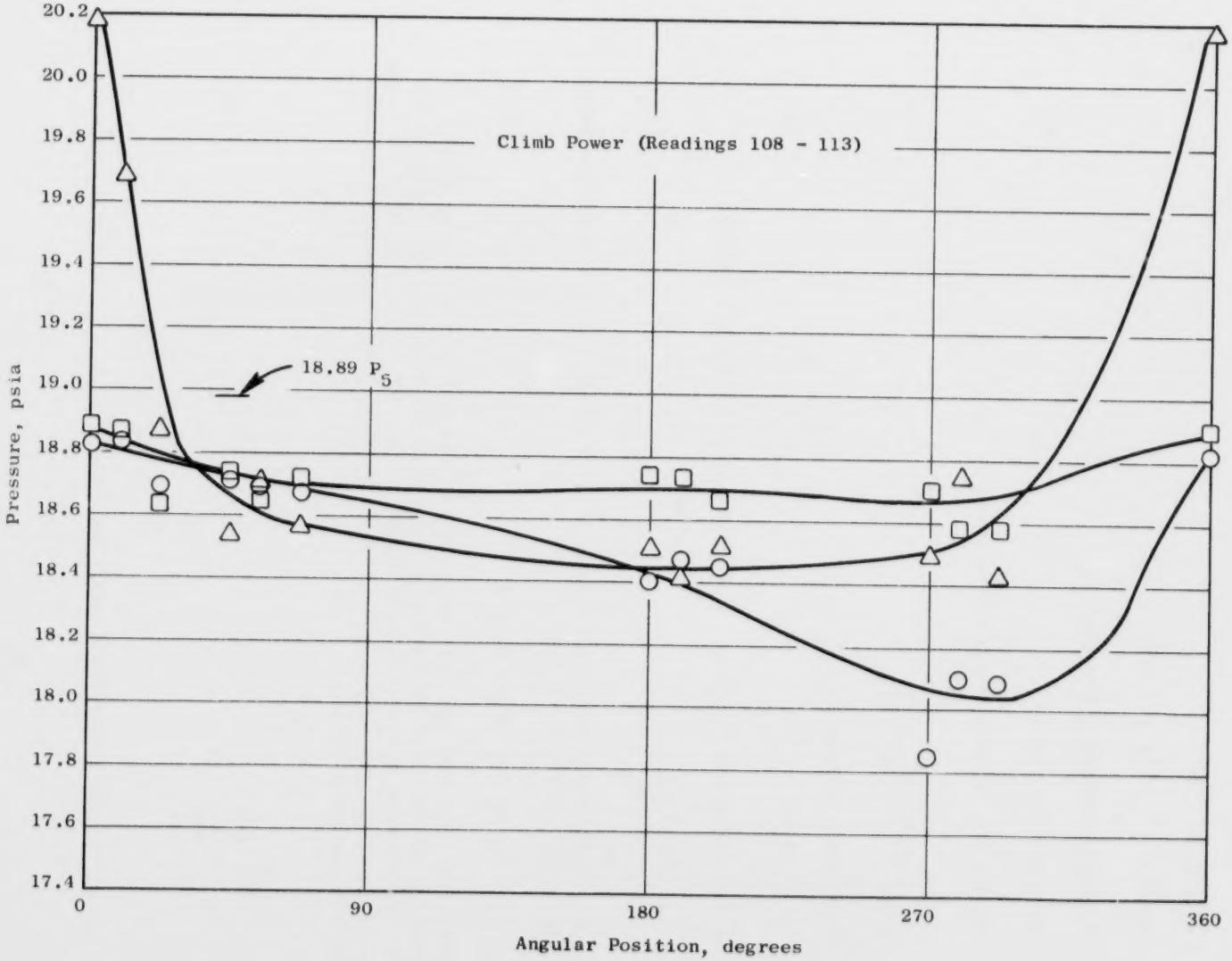

Figure 35. Climb Power Engine Exit Pressure Profiles.

Carbon Balance

$$W_s[C]_s = W_f[C]_f + W_c[C]_c \tag{6}$$

Enthalpy Balance (Constant C_p)

$$W_s T_s = W_f T_f + W_c T_c \tag{7}$$

Combining (5), (6), and (7) with $C_f = 0$,

$$\frac{[C]_s}{[C]_c} = \frac{T_s - T_f}{T_c - T_f} = \frac{W_c}{W_s} \tag{8}$$

For small values of C,

$$f_i \propto [C]_i \tag{9}$$

To a close approximation. Substituting Equation (9) into (8) gives:

$$\frac{f_s}{f_c} \simeq \frac{T_s - T_f}{T_c - T_f} \tag{10}$$

The sample flow was estimated based on incompressible-flow orifice equations. Individual orifice flow is:

$$W_i = A_e \sqrt{2\rho_i (P_i - P_{rake})} \tag{11}$$

where W_i is the flow through orifice i, A_e is the orifice effective area, ρ_i is the density of the mixture entering the orifice based on the exit temperature/pressure survey, P_i is the total pressure at the orifice inlet, and P_{rake} is the rake internal static pressure. Total sample flow is obtained by summing over the twelve orifices:

$$W_s = \sum_{i=1}^{12} W_i \tag{12}$$

The final sample temperature was computed as:

$$T_s = \sum_{i}^{N} W_i T_i / \sum_{i}^{N} W_i \tag{13}$$

where T_i is the inlet temperature at orifice i and N is the number of orifices which have sample flowing inward (at some conditions $P_i > P_{rake}$, and reverse flow can occur).

The above equations were used to solve for W_s and f_s/f_c for Rake B at several different angular positions and rake internal pressures. Results of these calculations are shown in Figure 36. These data are cross-plotted at a flow rate of 1.5 ft^3/min; this is the approximate sampling rate used during engine tests. As shown in Figure 37, predicted fuel/air ratios are in good agreement with experimental results.

The effect on measured emissions of sample dilution in the plyon wake is shown in Figures 38 and 39. CO and NO_x emission indices are generally within 10% of the average value in spite of fuel/air ratio variations of over 50%. A larger variation in HC levels is evident; however, this is magnified because of the very low HC levels obtained. At climb-out power, the variation in HC is not significant.

The large variation in smoke level at climb-out power does not appear to be related to the fuel/air ratio variation.

Since a complete set of data for all rake positions was only obtained on one test run, it is important to note the relationship between emissions data averaged over all rake positions and data obtained in the standard sampling mode. The standard procedure during engine tests was to obtain two samples, one each from Rakes A and B, with the overall rake assembly in the 0° position. A comparison of emissions obtained using this method with emissions averaged over a complete traverse is shown in Table 11. Differences of more than 10% in emissions indices measured with the two modes occur only in mid-to-high-power HC levels. As noted above, these large relative differences are due mainly to the very low HC levels measured at these conditions.

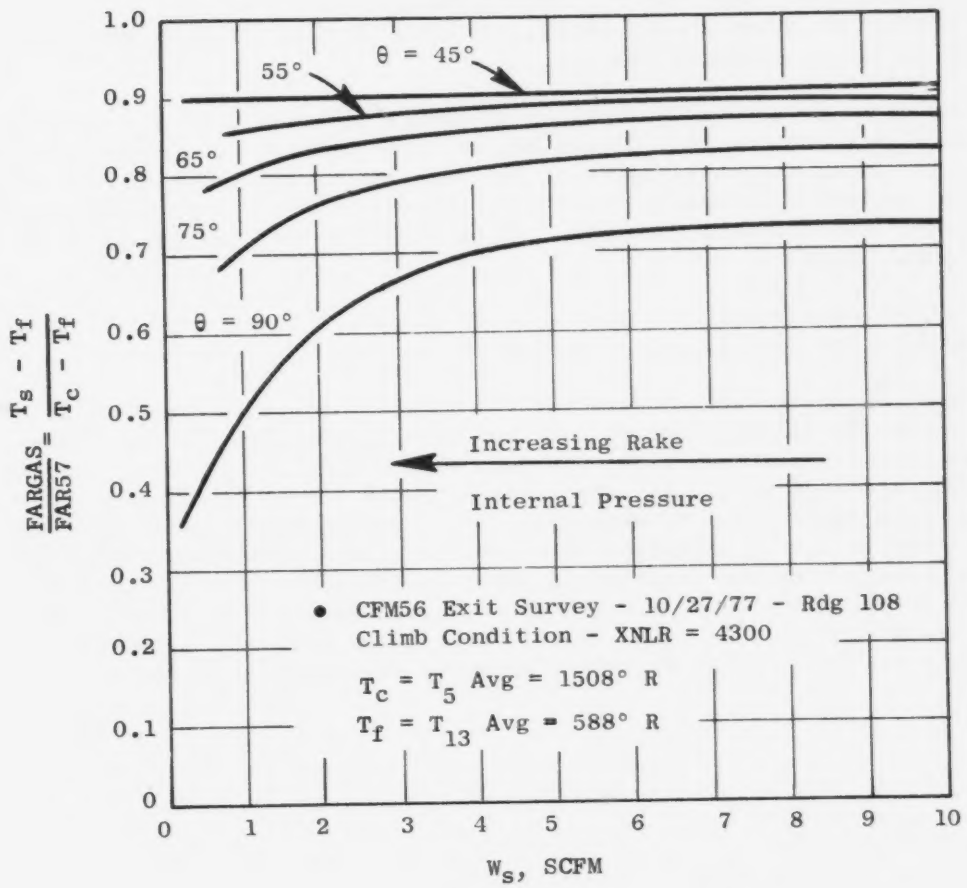

Figure 36. Effect of Flow Rate and Rake Angular Position on Sample Fuel/Air Ratio.

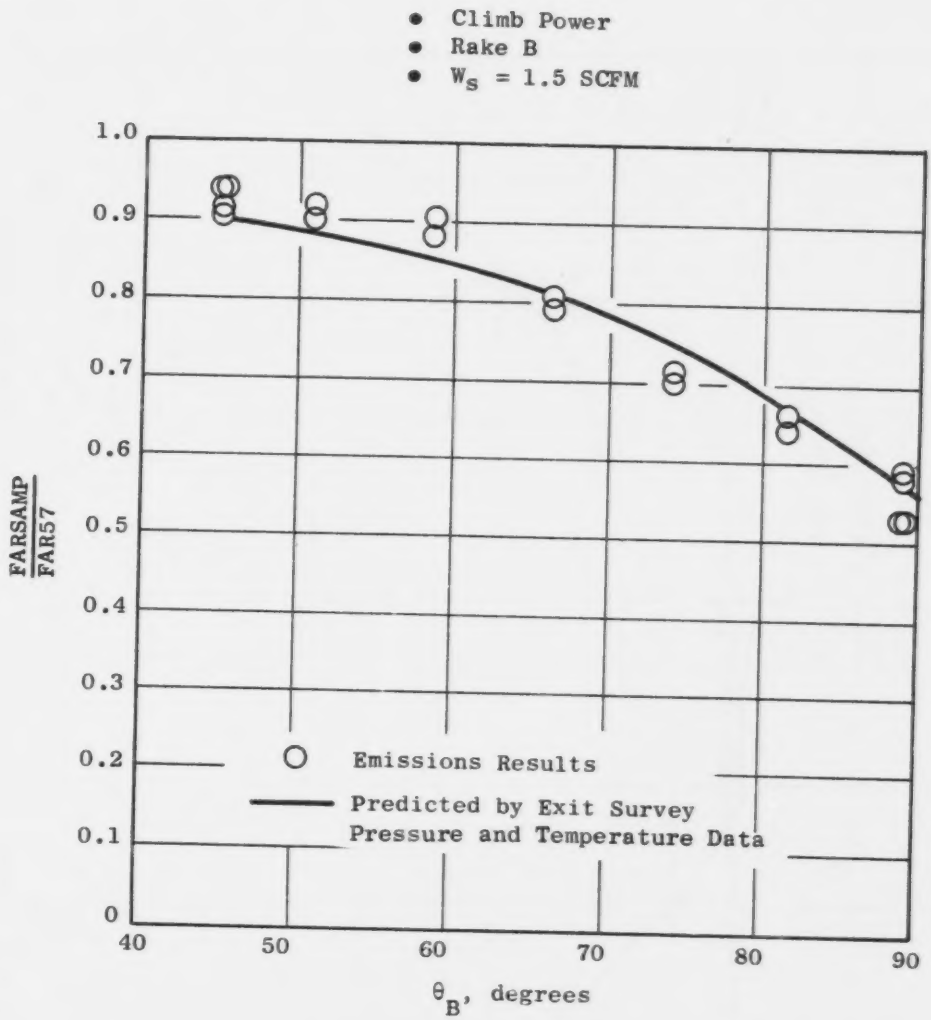

Figure 37. Comparison of Predicted and Experimental Sample Fuel/Air Ratio Profiles

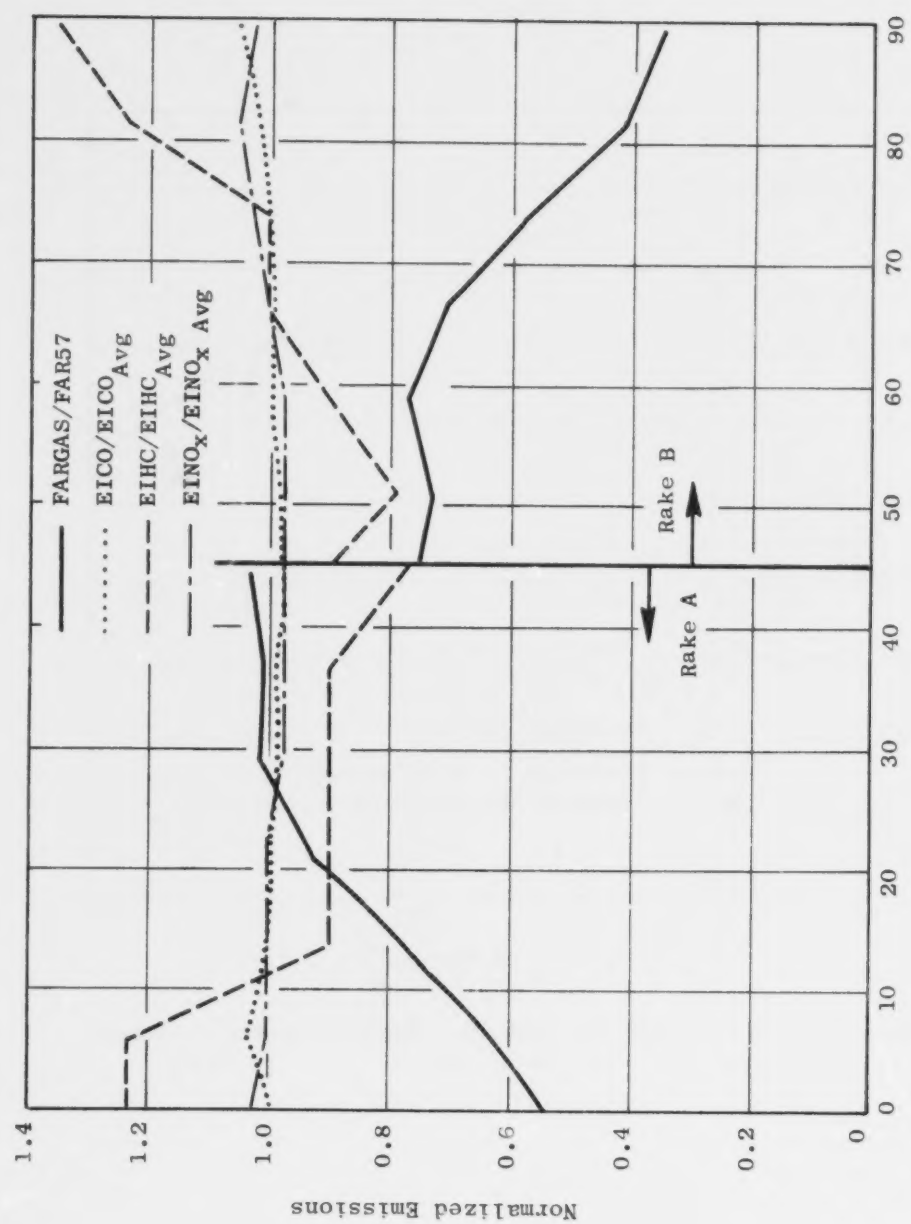

Figure 38. CFM56 Engine Tests - Idle Power Emissions Profiles.

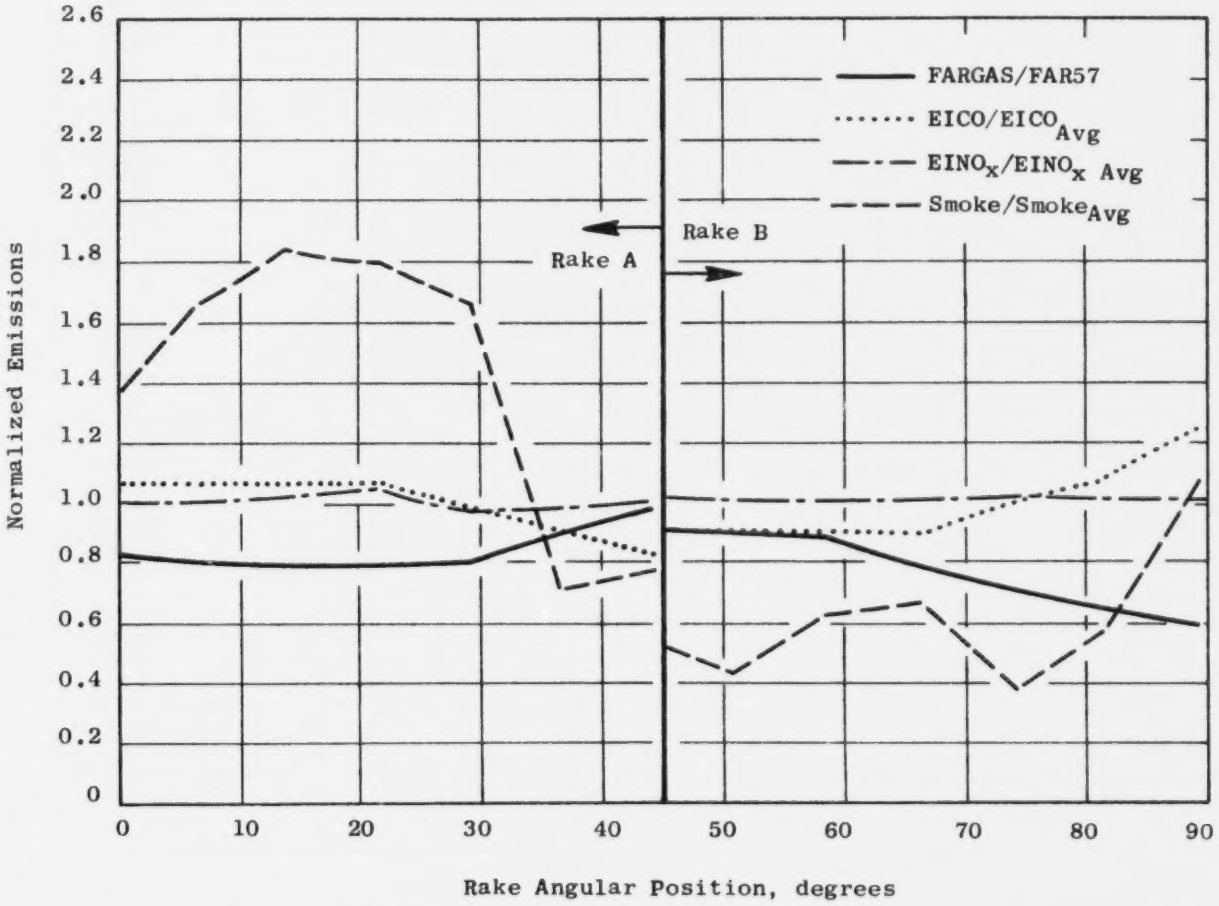

Figure 39. CFM56 Engine Tests - Climb Power Emissions Profiles.

Table 11. Comparison of Emissions Data for Complete Rake Traverse.

Condition - Parameter	Rake A-0	Rake B-0	Average of Rakes A-0 and B-0	Average of All 14 Readings	Standard Deviation	% Difference in A-0 and B-0 Average	Maximum Value	Minimum Value
Idle (Rdg. 242)								
EICO, lb/1000 lb	29.30	29.00	29.20	29.46	0.61	-0.9	30.90	28.70
EIHC	1.10	0.80	0.95	0.89	0.16	6.7	1.20	0.70
$EINO_x$	4.10	3.90	4.00	3.99	0.10	0.2	4.20	3.90
Smoke	2.8	2.8	2.8	---	---	---	---	---
FARGAS	0.00590	0.00817	0.00704	0.00793	0.00236	-11.2	0.01120	0.00377
1.5 Idle (Reg. 245)								
EICO	17.30	15.90	16.60	16.55	0.97	0.3	17.70	13.90
EIHC	0.40	0.20	0.30	0.28	0.11	7.1	0.50	0.20
$EINO_x$	4.80	4.80	4.80	4.76	0.19	0.8	4.90	4.10
Smoke	2.1	1.3	1.70	---	---	---	---	---
FARGAS	0.00589	0.00811	0.00700	0.00796	0.00221	-12.1	0.01101	0.00460
Approach (Rdg. 250)								
EICO	5.50	4.80	5.15	5.29	0.49	-2.7	6.60	4.70
EIHC	0.10	0.10	0.10	0.14	0.06	-28.6	0.30	0.10
$EINO_x$	8.20	8.50	8.35	8.63	0.17	-3.2	8.90	8.20
Smoke	2.8	2.2	2.5	---	---	---	---	---
FARGAS	0.00748	0.01023	0.00886	0.00909	0.00220	-2.5	0.01243	0.00494
Climb (Rdg. 255)								
EICO	1.30	1.00	1.15	1.23	0.15	-6.5	1.40	1.00
EIHC	0.10	0.10	0.10	0.12	0.06	-16.7	0.20	0
$EINO_x$	14.00	14.10	14.05	14.12	0.18	-0.5	14.40	13.70
Smoke	9.3	3.1	6.2	---	---	---	---	---
FARGAS	0.01619	0.01785	0.01702	0.01574	0.00220	8.1	0.01935	0.01123
Takeoff (Rdg. 258)								
EICO	1.20	1.00	1.10	1.13	0.13	-2.7	1.40	0.90
EIHC	0.10	0.10	0.10	0.12	0.04	-16.7	0.20	0.10
$EINO_x$	16.70	16.70	16.70	17.00	0.30	-1.8	17.60	16.70
Smoke	11.4	5.6	8.5	---	---	---	---	---
FARGAS	0.01824	0.01955	0.01890	0.01724	0.00228	9.6	0.02030	0.01229

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